MM208
THEORY OF METAL FORMING

Presented by : SHREYAS TIWARI
JITENDRA SAHU
VAMSHI KRISHNA RAO
VYANKATESH CHAVAN

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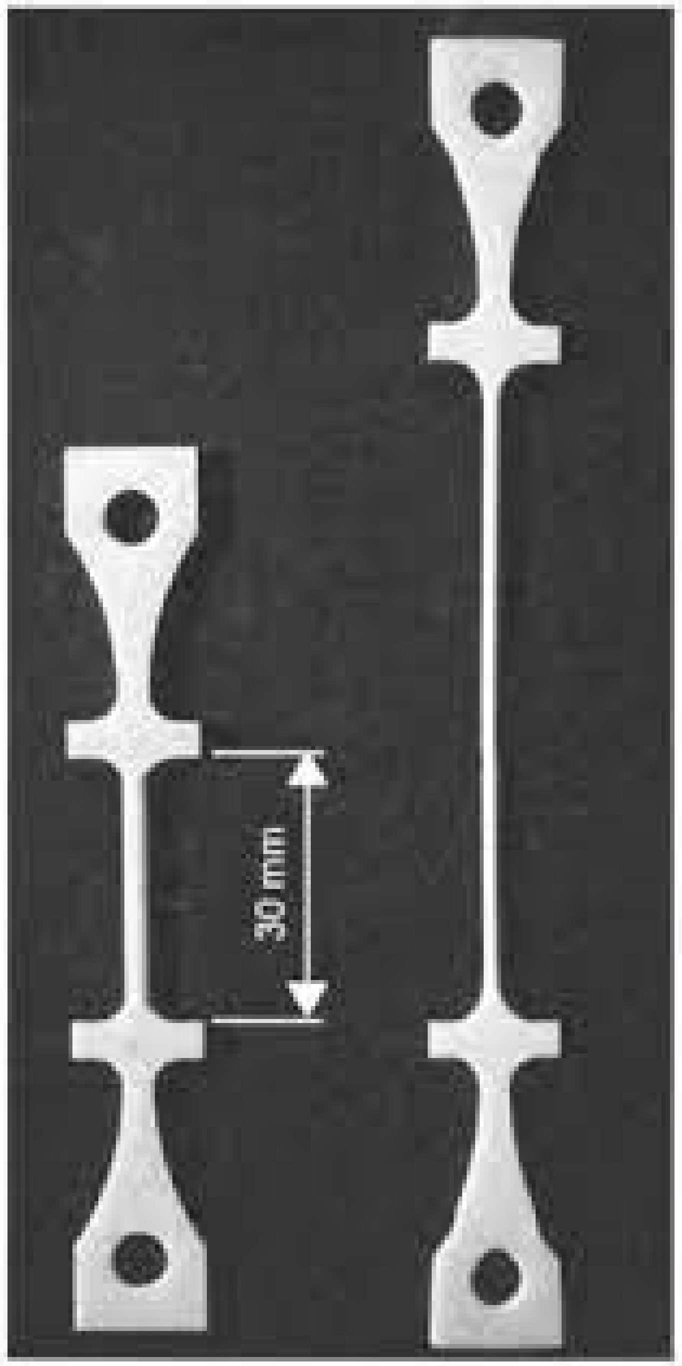
INTRODUCTION

Superplastic materials are polycrystalline solids which can undergo **exceptionally large tensile strains** prior to failure, when they are deformed under a limited range of conditions. Numerous metallic materials in uniaxial tension can show elongations anywhere from 300 – 1000% or more.

CONDITION FOR SUPERPLASTICITY

- **Very slow strain rate** during deformation. This strain rate varies from 0.0001 to 0.001 per second.
- During deformation the **temperature is high** of nearly about 0.7 - 0.8 time its melting point.
- The **microstructure of material should be extremely fine grain size** (a few micrometers or less), with generally uniform and equiaxed grain structure

grain size that results is typically between 5 to 15 micrometers.

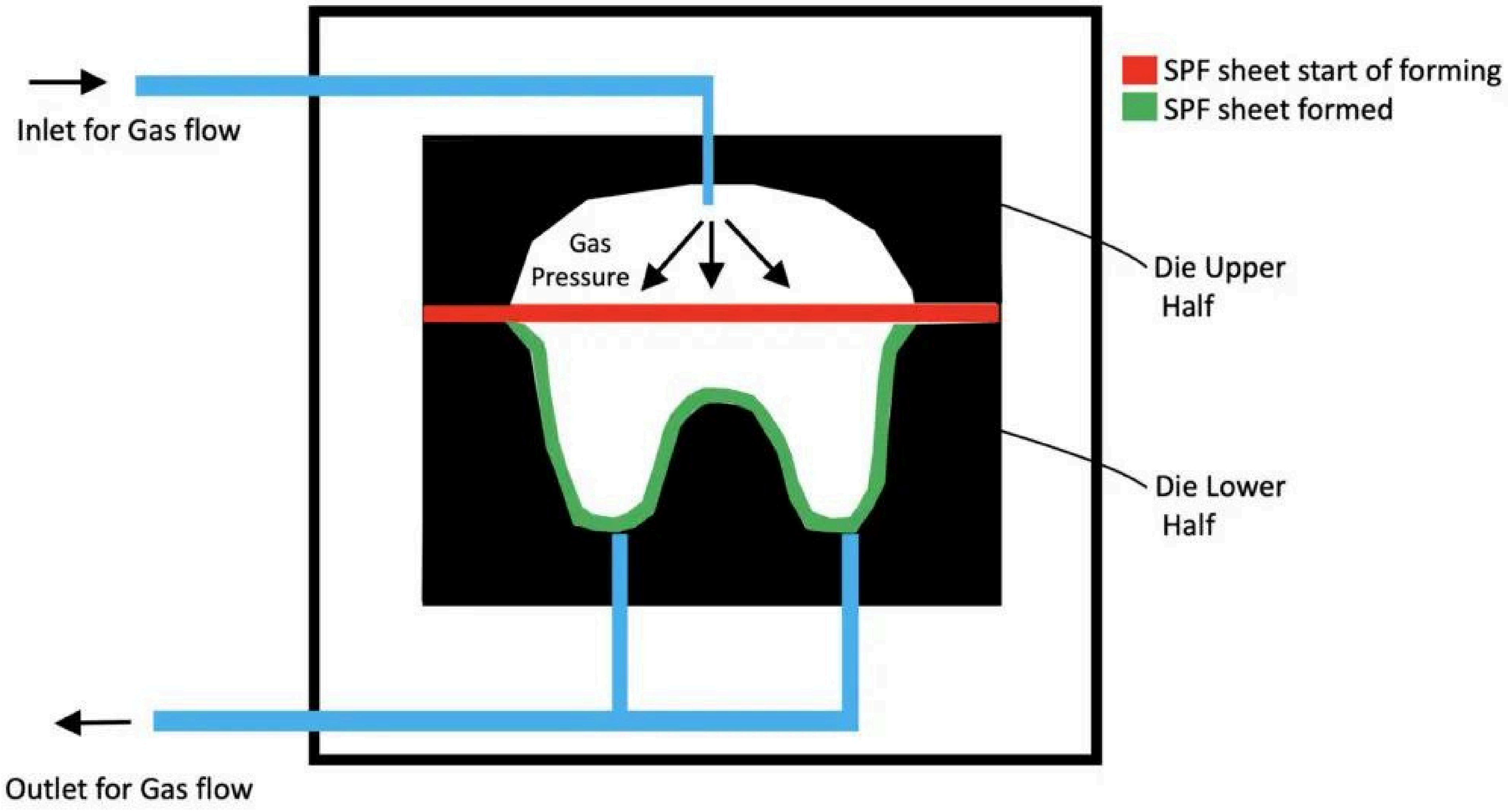


SUPERPLASTIC FORMING (SPF) PROCESS

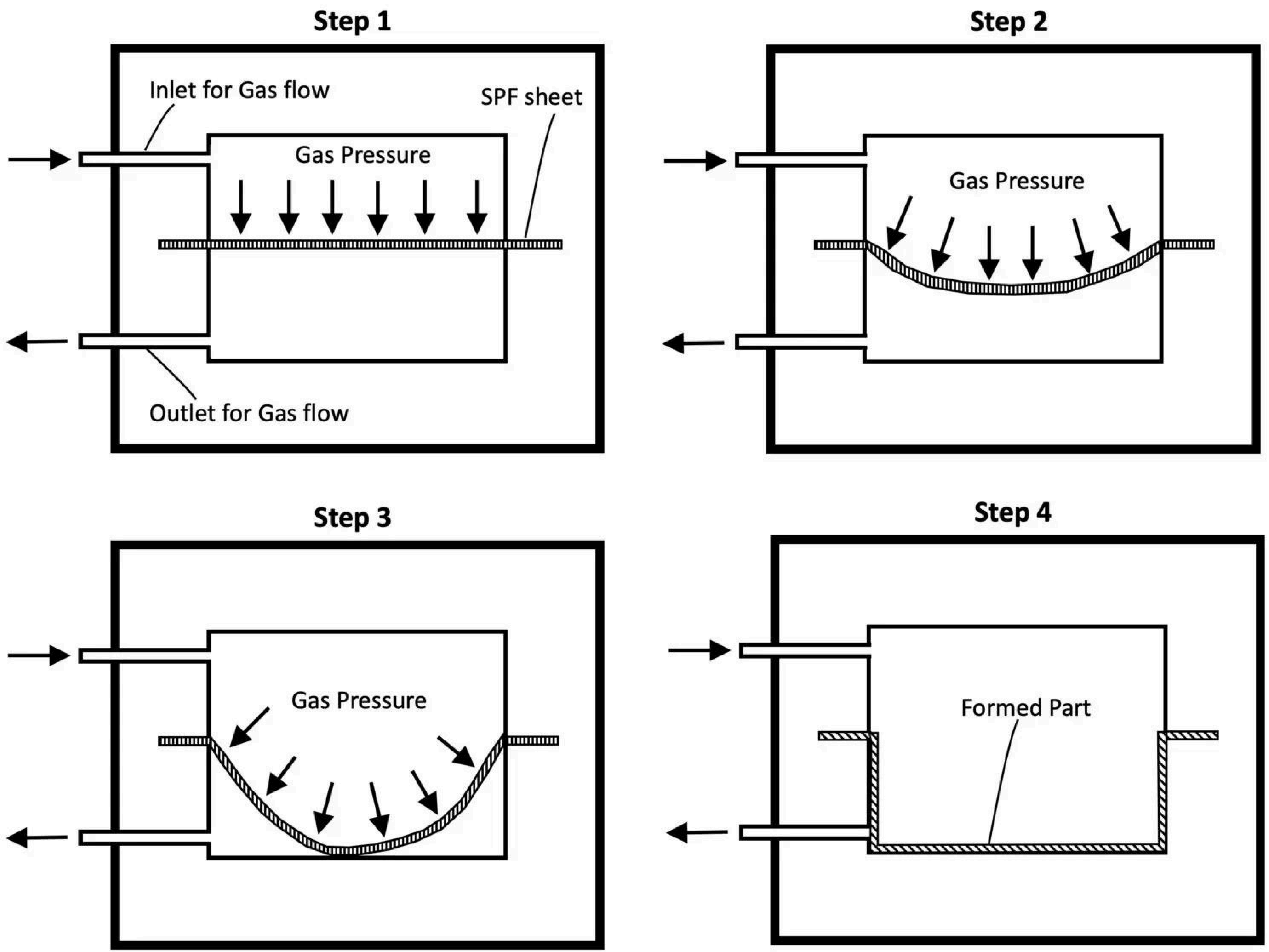
A metal forming technique known as "**Superplastic forming**" uses the metallurgical phenomena of "**Superplasticity**" to create intricate and highly curved sheet metal pieces. In the SPF process, thin sheets of metallic materials or alloys are gas pressure blown into dies at high temperatures to create objects with complicated geometries and the necessary thickness. While other SPF procedures may employ air with or without a hoover, others may use hoover systems with Argon gas. The desired forming speed and part thickness are attained using variable gas pressure time curves.

SUPERPLASTIC BLOW FORMING OF METAL SHEETS

SINGLE SHEET BLOW FORMING

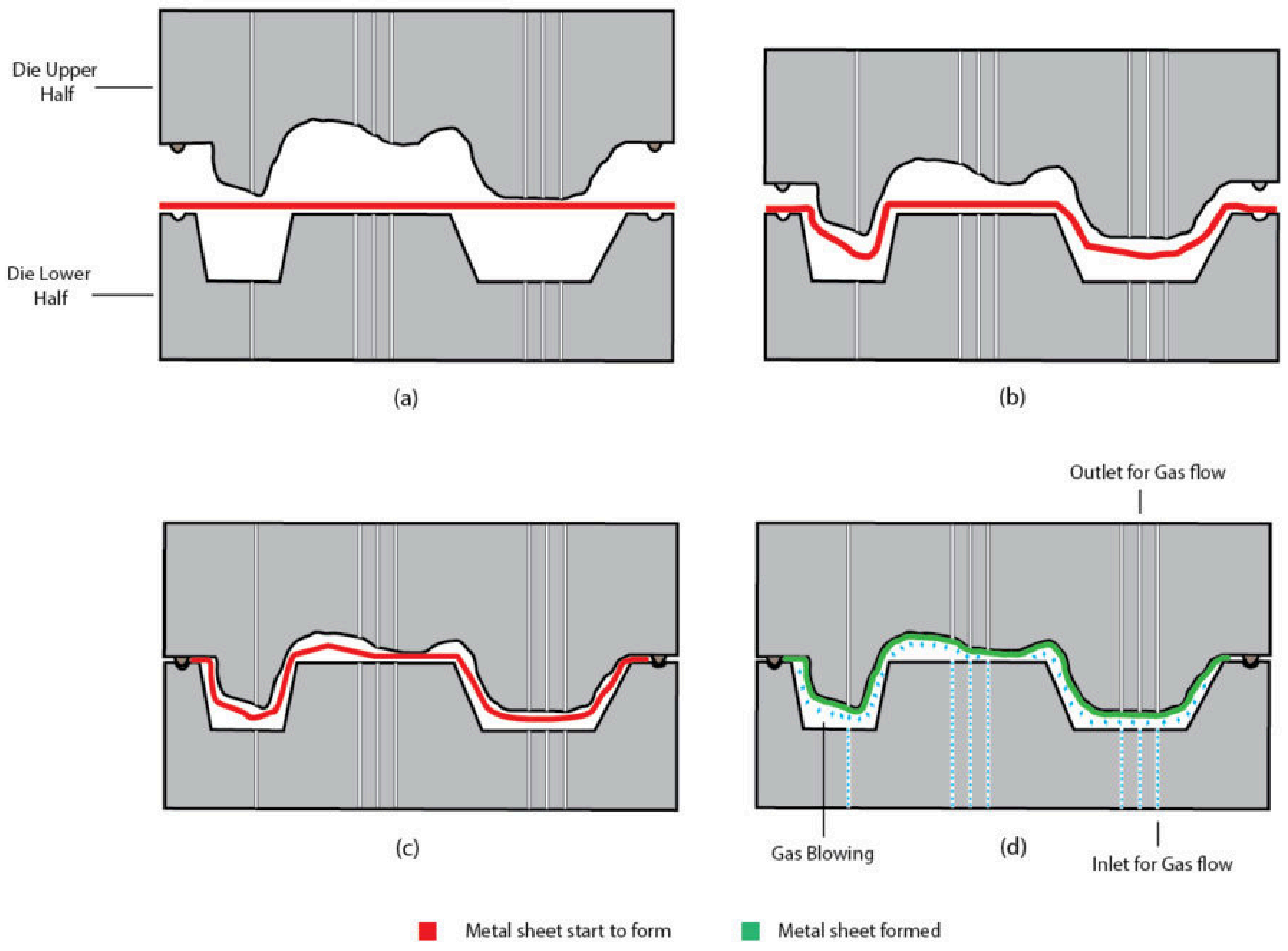


Blow forming can manufacture single sheet alloys into highly complex shapes that artistically styled or designed for structural support. This process is performed in one operation, thus reducing the number of joining operations required. Based on application of a gas pressure differential on the superplastic sheet, resulting in deformation of the material into a particular die configuration.


Step 1
Inlet for Gas flow
SPF sheet
Gas Pressure
Outlet for Gas flow
Step 2
Gas Pressure
Step 3
Gas Pressure
Step 4
Formed Part

SUPERPLASTIC BLOW FORMING OF METAL SHEETS

HIGH-SPEED BLOW FORMING (HSBF)



The SPF technology can be combined with crash or draw forming to create a novel sheet metal forming technique called the High-Speed Blow Forming process (HSBF). This technique allows for forming complex parts at high rates taking advantage of the best benefits of each technology

ADVANTAGES OF SPF

- Cost saving from multiple components formed in a single part
- Multiple components can be produced in one operation
- Capacity to produce larger, stronger, and lighter parts without joints and welds
- Little spring back
- One tool required

DISADVANTAGES OF SPF

- High working temperature
- Non uniform thickness distribution when operating at higher strain rates
- Relatively slower manufacturing process as compared to stamping, warm forming, and hydroforming
- Heated and formed materials such as aluminum are susceptible to a wearing or galling

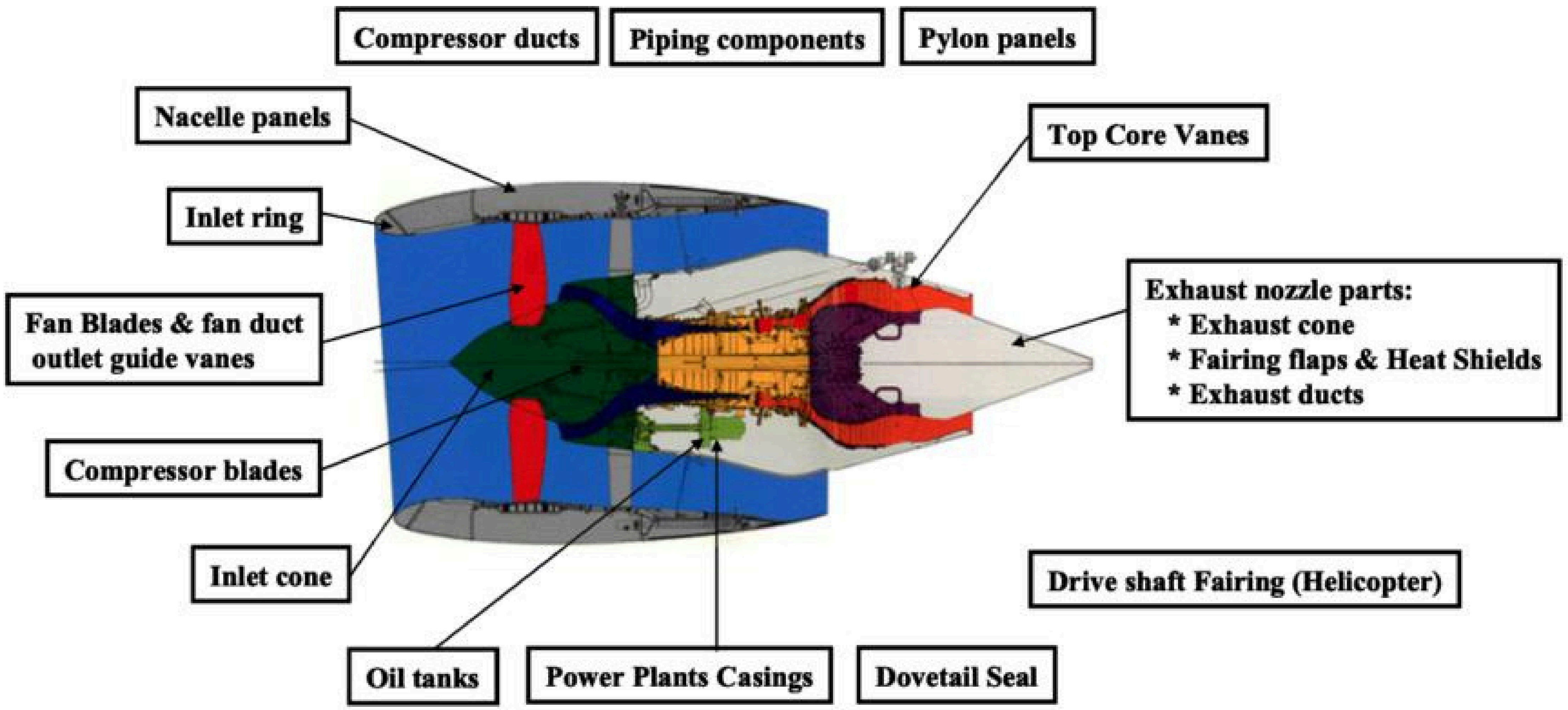
TYPES OF SUPERPLASTIC MATERIALS

A material which exhibits superplastic behaviour must be capable of being processed so as to produce fine grain equiax microstructures that stay stable at a superplastic deformation rate, where the grain boundary sliding mechanism is an important characteristic of this kind of flow

- Aluminum alloy AA5083 is a relatively inexpensive material used extensively to produce automotive panels at 450°C– 480°C.
- Magnesium alloy AZ31 is the lightest structural metallic material used to produce automotive panels at 425°C.
- Titanium alloy Ti-Al-4V is processed at 900°C and finds extensive use in aerospace applications because of its specific high temperature strength

TITANIUM ALLOY TI-AI-4V

The titanium alloy superplastic forming process is also used in the production of the F15 fighter's heat shield, engine nozzles, landing gear doors, and the upper part of the rear fuselage, which reduces the weight of the F-15 fighter by 72.6Kg.



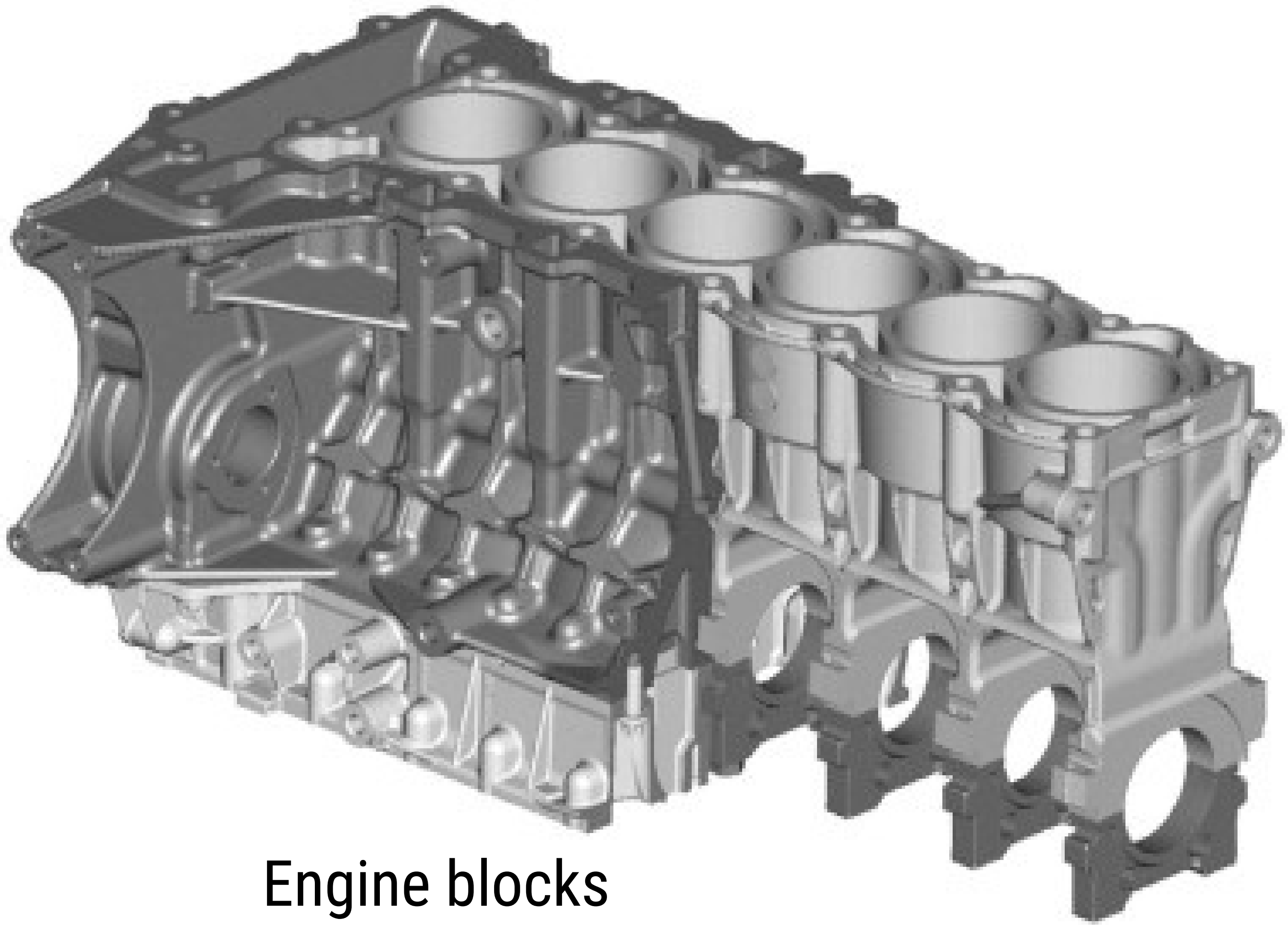
ALUMINUM ALLOY AA5083

Aluminium 5083 is used in Shipbuilding, Rail cars, Vehicle bodies, Tip truck bodies. It is commonly used in cargo floor panels due to its high strength, corrosion resistance, and low weight.

Automotive body side left hand panel manufactured from Hydro Aluminum A5083 alloy at 450°C

MAGNESIUM ALLOY AZ31

Magnesium alloy AZ31 is a commonly used magnesium alloy with good strength and corrosion resistance. It is commonly used in automotive components such as engine blocks or hoods because it offers good heat resistance and low weight, which improves fuel efficiency.



Engine blocks

PROCESSING MAPS OF ZIRCONIUM AND ITS ALLOY

WHAT IS A PROCESSING MAP?

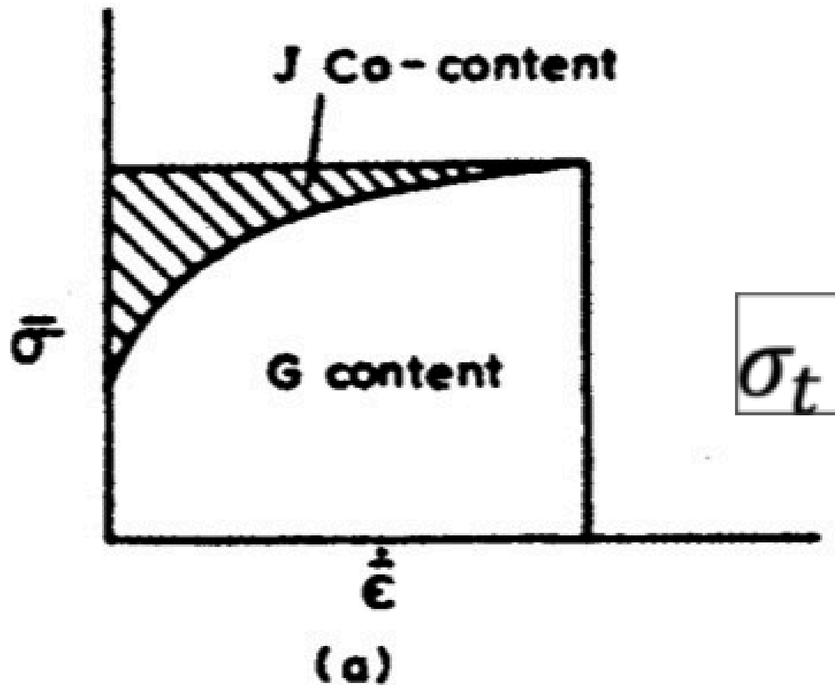
PROCESSING MAPS IS A **GRAPHICAL REPRESENTATION** THAT SHOWS THE RELATIONSHIP BETWEEN THE **PROCESSING PARAMETERS** SUCH AS STRAIN RATE, TEMPERATURE TO THE RESULTING MATERIALS FLOW STRESS AND **STRAIN RATE SENSITIVITY**

POWER DISSIPATION MAP

In metal forming processes, power dissipation refers to the amount of energy that is transformed into heat and microstructural dissipation due to the deformation of the metal. A power dissipation map is a tool used to **visualize the distribution of power dissipation** throughout the metal during the forming

$$P = \int_0^{\dot{\bar{\varepsilon}}} \bar{\sigma}.d\dot{\bar{\varepsilon}} + \int_0^{\bar{\sigma}} \dot{\bar{\varepsilon}}.d\bar{\sigma} = G + J$$

the **first integral is called G content** due to heat dissipation and the **second one a J co-content** due to microstructure dissipation since it is a complementary part of G content.



$$\sigma_t = C\dot{\varepsilon}_t{}^m$$

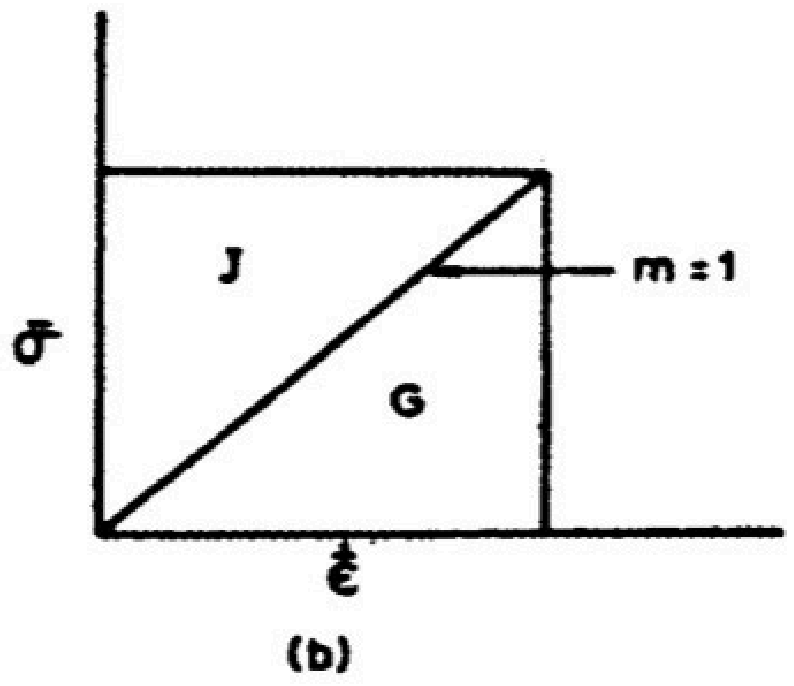


Fig. 1.3 (a) Schematic representation of the constitutive equation in a non-linear power dissipator (b) Ideal linear dissipator.

EFFICIENCY OF POWER DISSIPATION

Efficiency parameter describes the **relative rate of entropy production** occurring during hot deformation due to a microstructural change in the system.

$$\frac{J}{J_{MAX}} = \frac{m/(m+1)}{1/2} = \frac{2m}{m+1} \equiv \eta$$

$$\Delta J / \Delta G = m$$

$$\Delta J / \Delta P = m/(m+1)$$

- The value of m for stable flow in a viscoplastic solid is between 0 and 1
- The value of m less than one (commonly known as negative strain rate sensitivity) is observed for the process of dynamic strain aging .

The efficiency parameter (η) may be plotted as a function of temperature and strain rate to obtain the power dissipation map

INSTABILITY MAP

An instability map in metal forming is a tool that is used to **predict the occurrence of various types of instabilities** during the forming process, such as wrinkling, necking, and tearing.

$$\xi(\dot{\bar{\varepsilon}}) = \frac{\partial \ln(m / m+1)}{\partial \ln \dot{\bar{\varepsilon}}} + m \quad > 0$$

PROCESSING MAP

The **instability map** may be **superimposed** on the **power dissipation map** to obtain a processing map in which the limits for the unstable flow regime are clearly marked

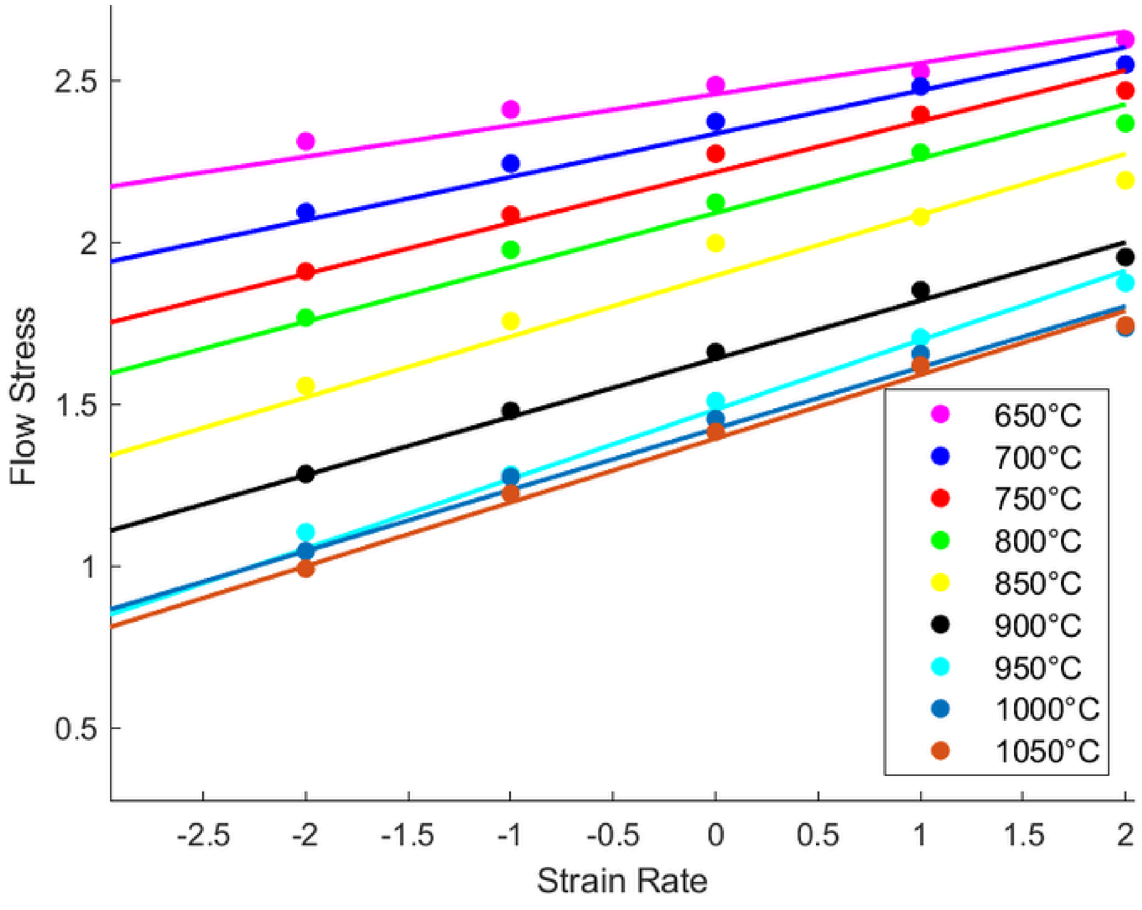
Zr-1Nb-1Sn

Material: Zr-1Nb-1Sn alloy

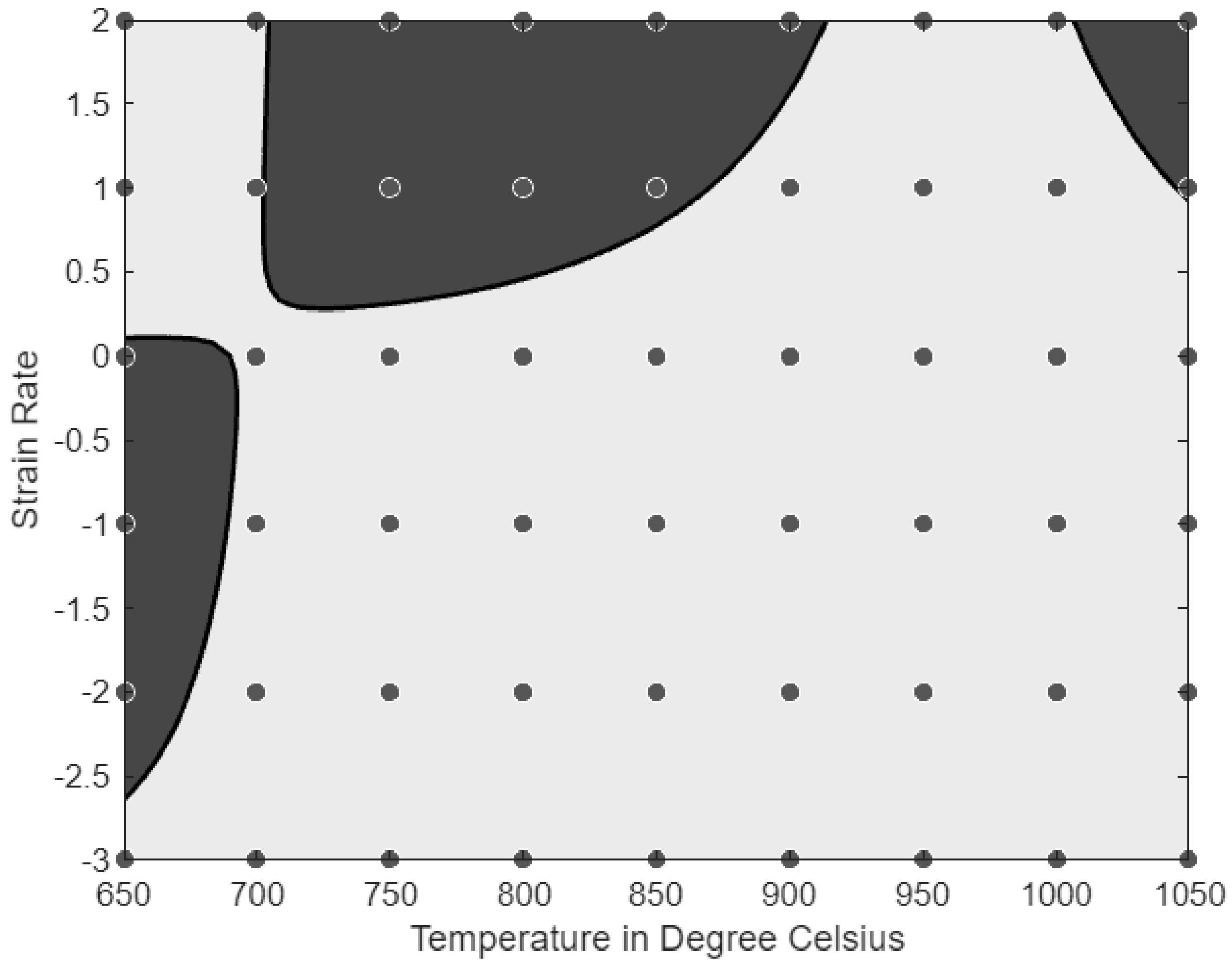
Composition: Nb -1, Sn - 1, O - 0.12 ,Zr - Bal.

Prior History: Extruded and cold drawn rods β treated at 1020°C for 30 min and water quenched. The microstructure was β transformed with acicular morphology within large β grains.

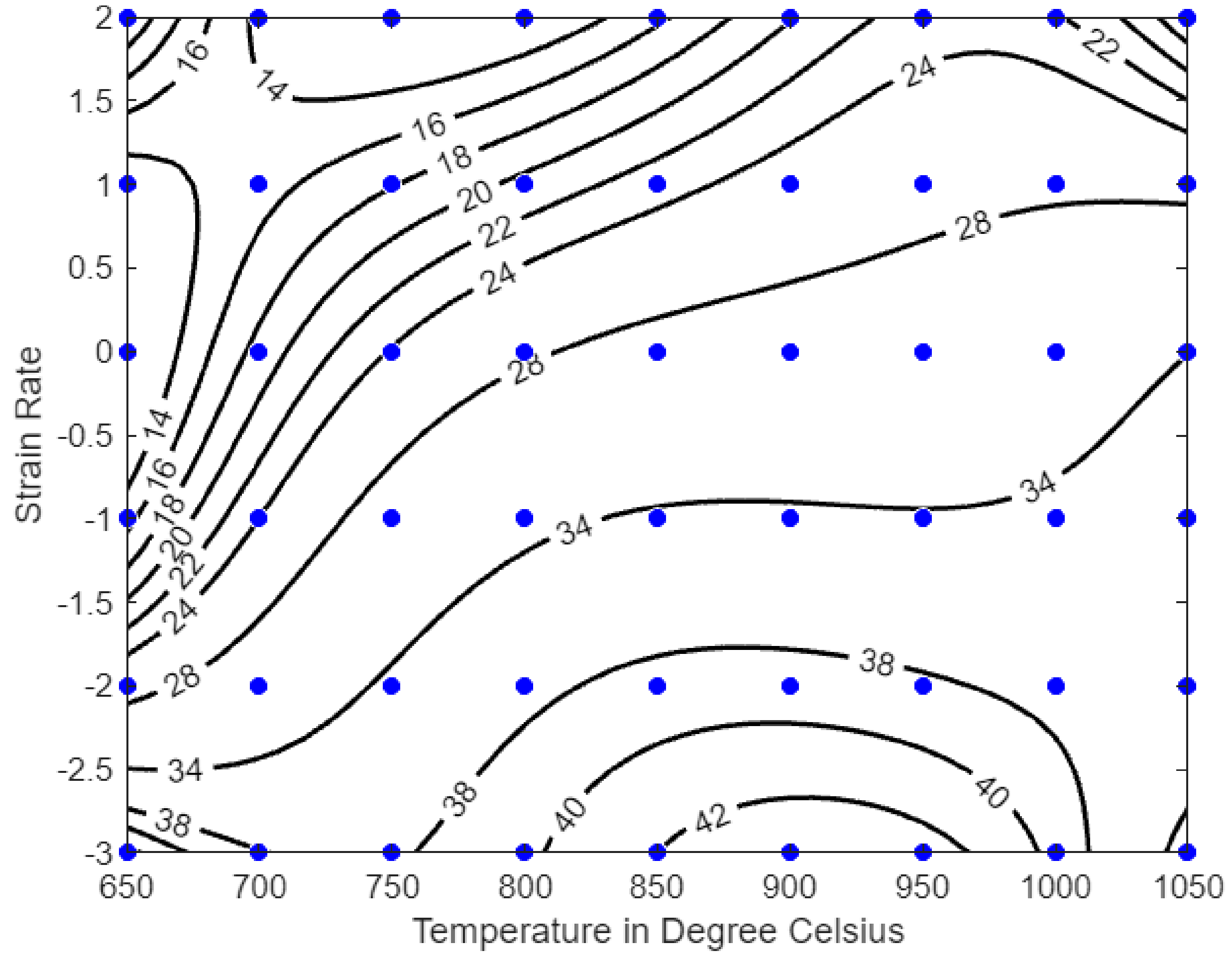
FLOW STRESS VS STRAIN RATE



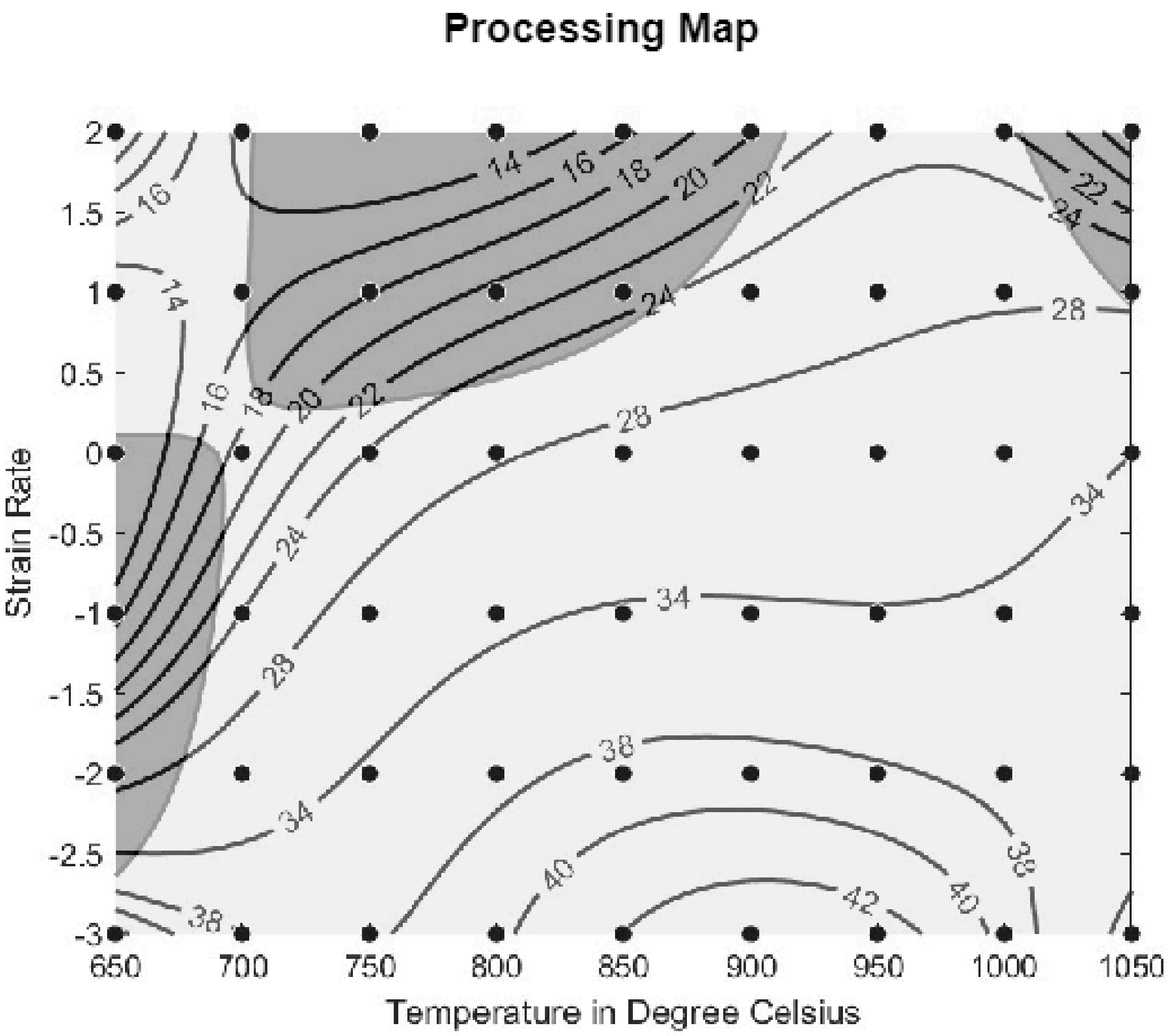
INSTABILITY MAP



POWER DISSIPATION MAP



PROCESSING MAP



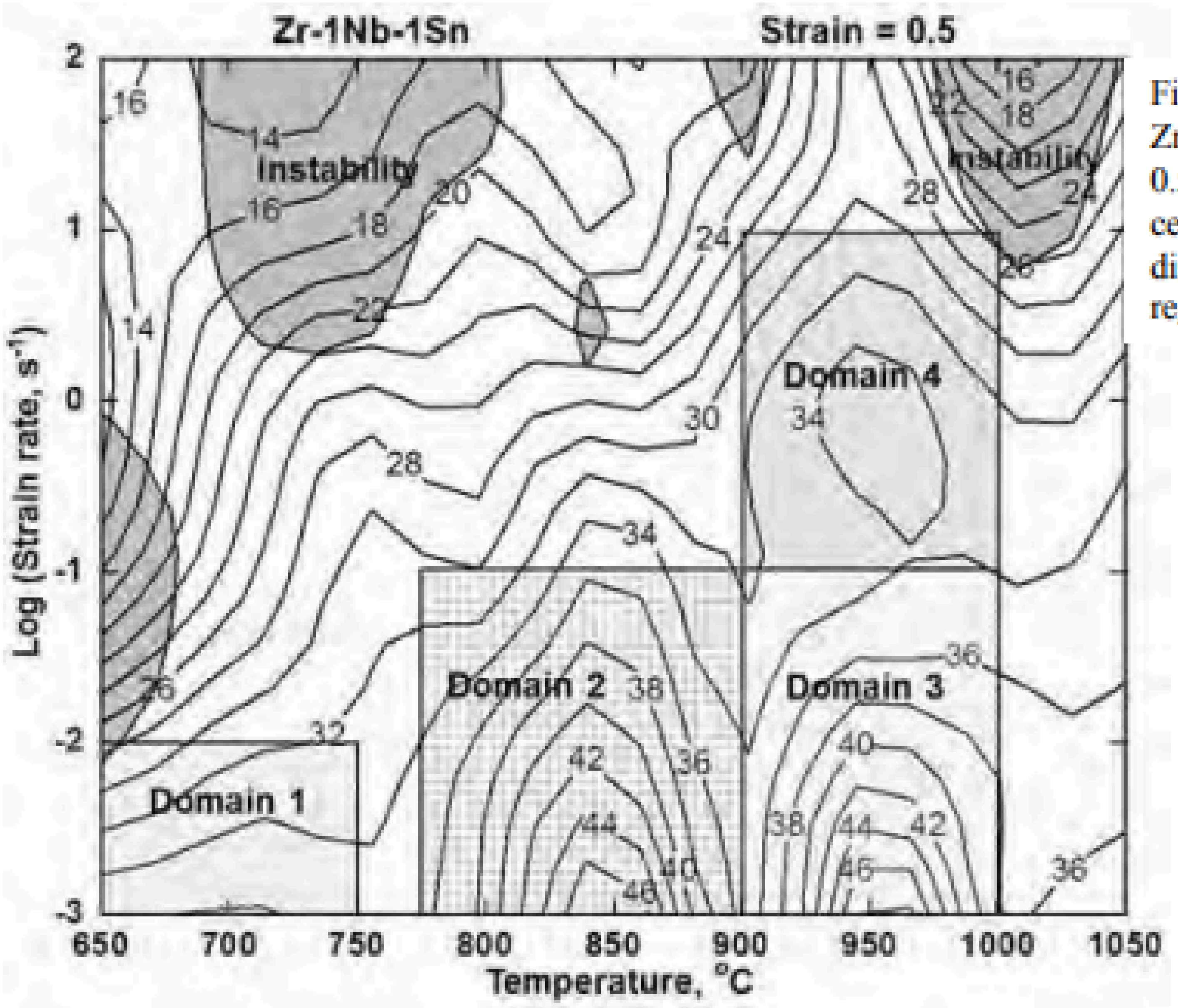
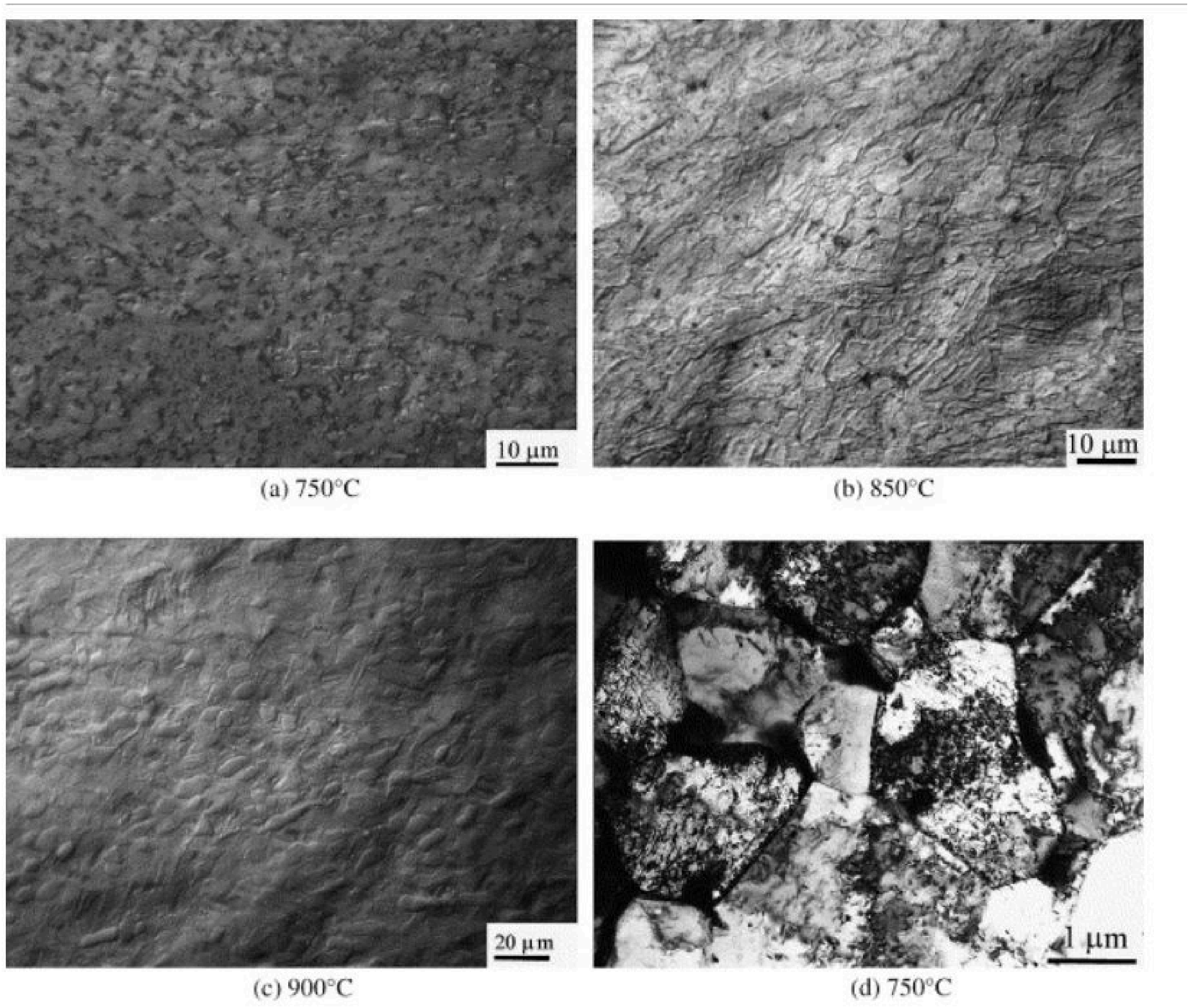


Fig. 8.4.1 Processing Map for Zr-1Nb-1Sn alloy at a strain of 0.5. Numbers represent per cent efficiency of power dissipation. The instability regime is marked.

Metallurgical Interpretation and Processing Conditions

Manifestation	Temperature, °C	Strain rate, s^{-1}
Dynamic recovery of α	650 - 750	0.001 - 0.01
Spherodization	775 - 900	0.001 - 0.1
Superplasticity	800 -1000	0.001 - 0.1
DRX of β	900 - 1000	0.1 - 10
Flow instability	700 - 1000	> 3
	<700	> 0.01
Optimum Conditions:	**850 °C/0.001 s^{-1} or 950 °C/ 1s^{-1}**	

Optical micrographs of Zr-1Nb-1Sn



(a) 750°C (b) 850°C (c) 900°C (d) 750°C

Fig. 4. Microstructure of samples deformed to ε=0.7 and at $\dot{\varepsilon} = 10^{-3}\ s^{-1}$ and at various temperatures as indicated: (a–c) are optical micrographs showing equiaxed morphology of α grains, a change in α grain size with temperature is seen, and (d): TEM micrograph showing dislocation substructure within α grains and presence of β at the triple junction of grains.

Fig. 6. Optical microstructure of samples deformed to ε=0.7 at 700°C and $10^1 s^{-1}$ in the unstable flow regime. Localized deformation bands are seen here. The compression axis is vertical.

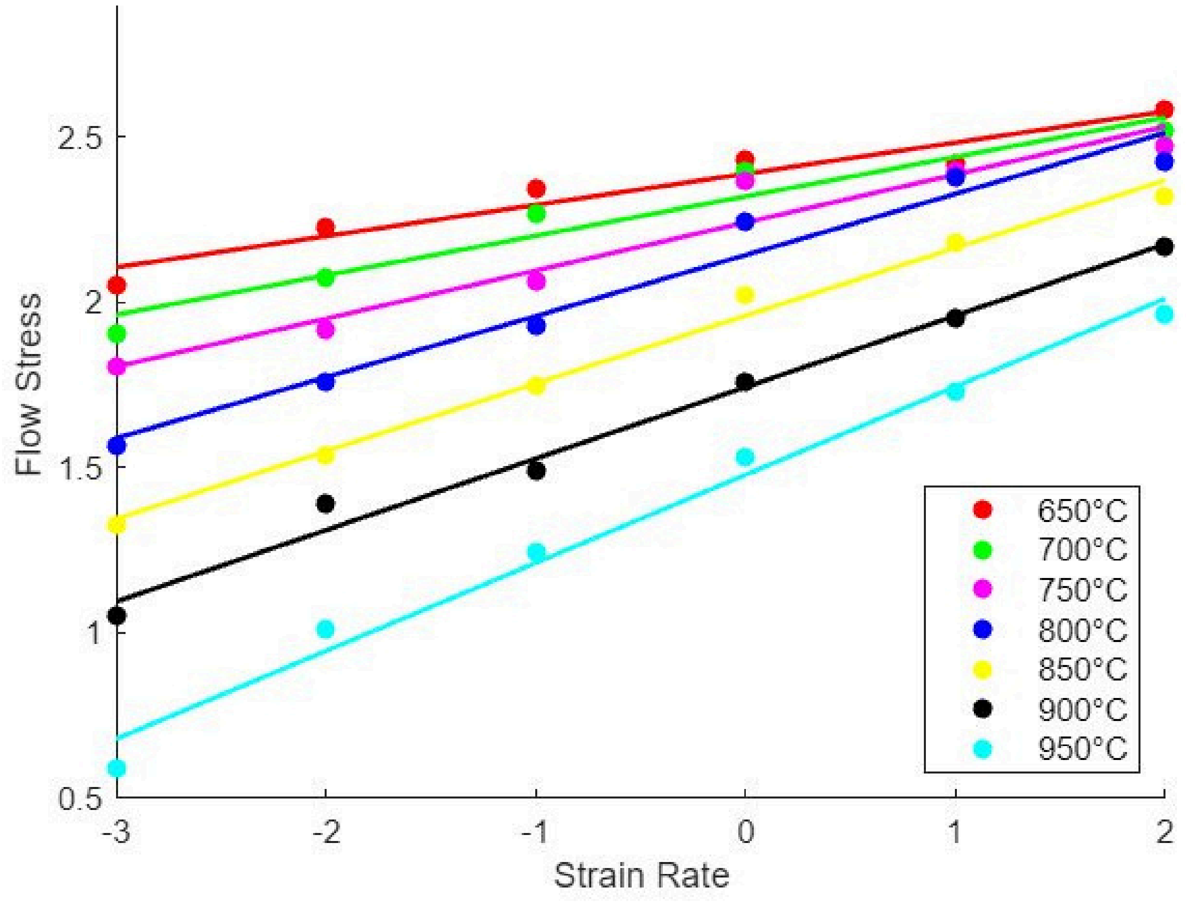
Zircaloy-2

Material: Zircaloy-2 (beta quenched)

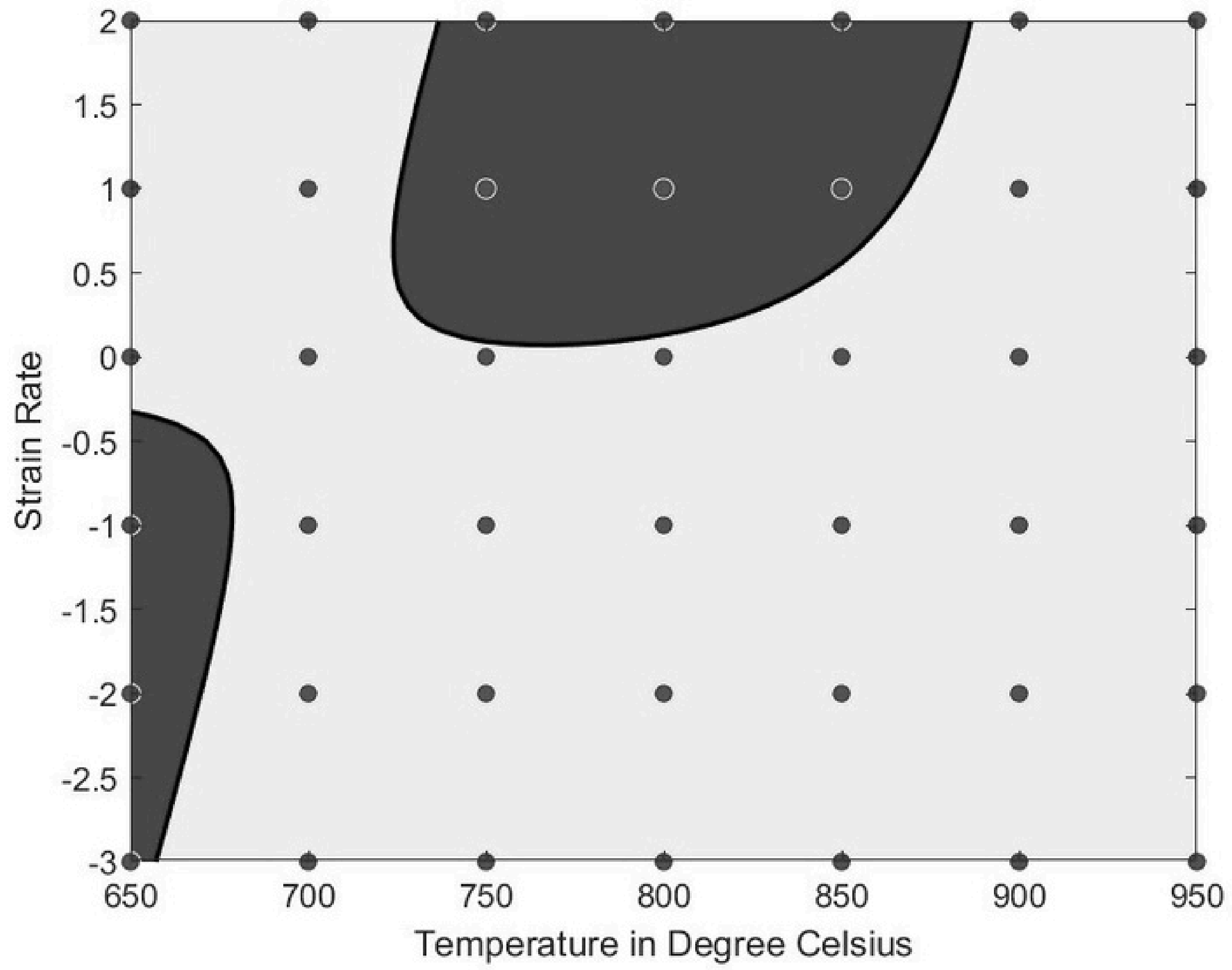
Composition: Sn: 1.3-1.6, Fe: 0.07-0.2, Cr: 0.05- 0.15, Ni: 0.03-0.08, O: 1000-1300 ppm, N: < 80 ppm, Zr: bal.

Prior History: Extruded and cold drawn rods were beta quenched from 1040°C after sealing them in silica tubes under helium atmosphere.

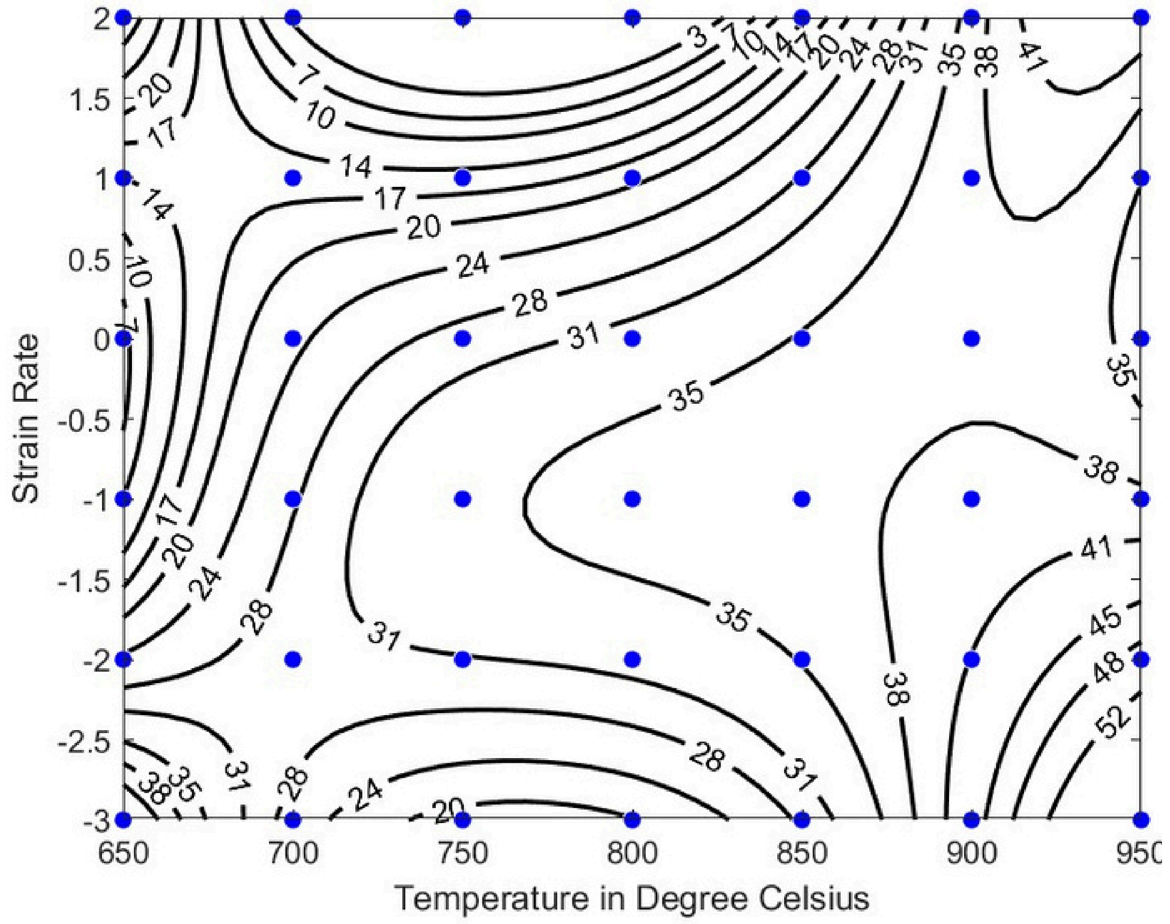
FLOW STRESS VS STRAIN RATE



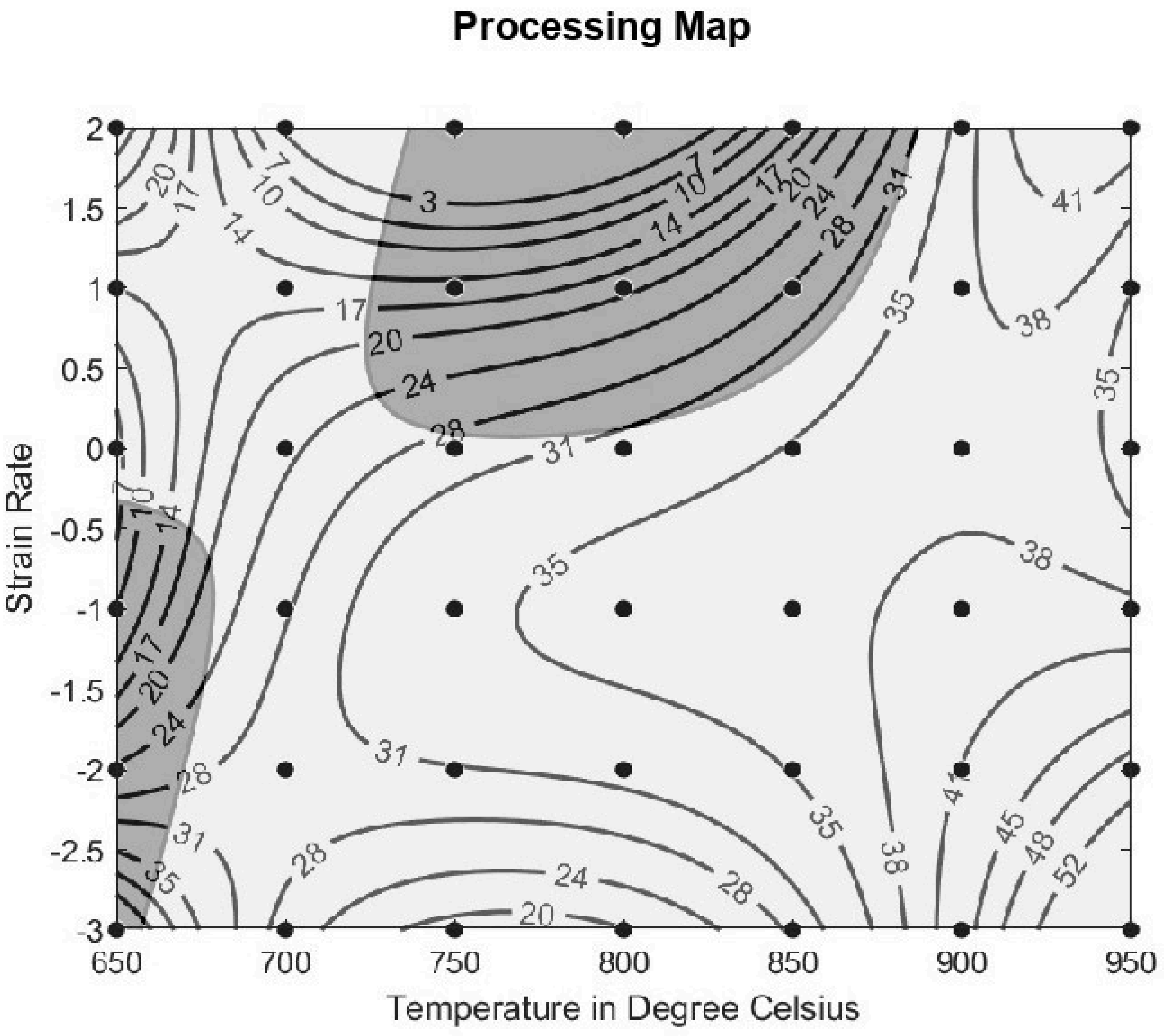
INSTABILITY MAP



POWER DISSIPATION MAP



PROCESSING MAP



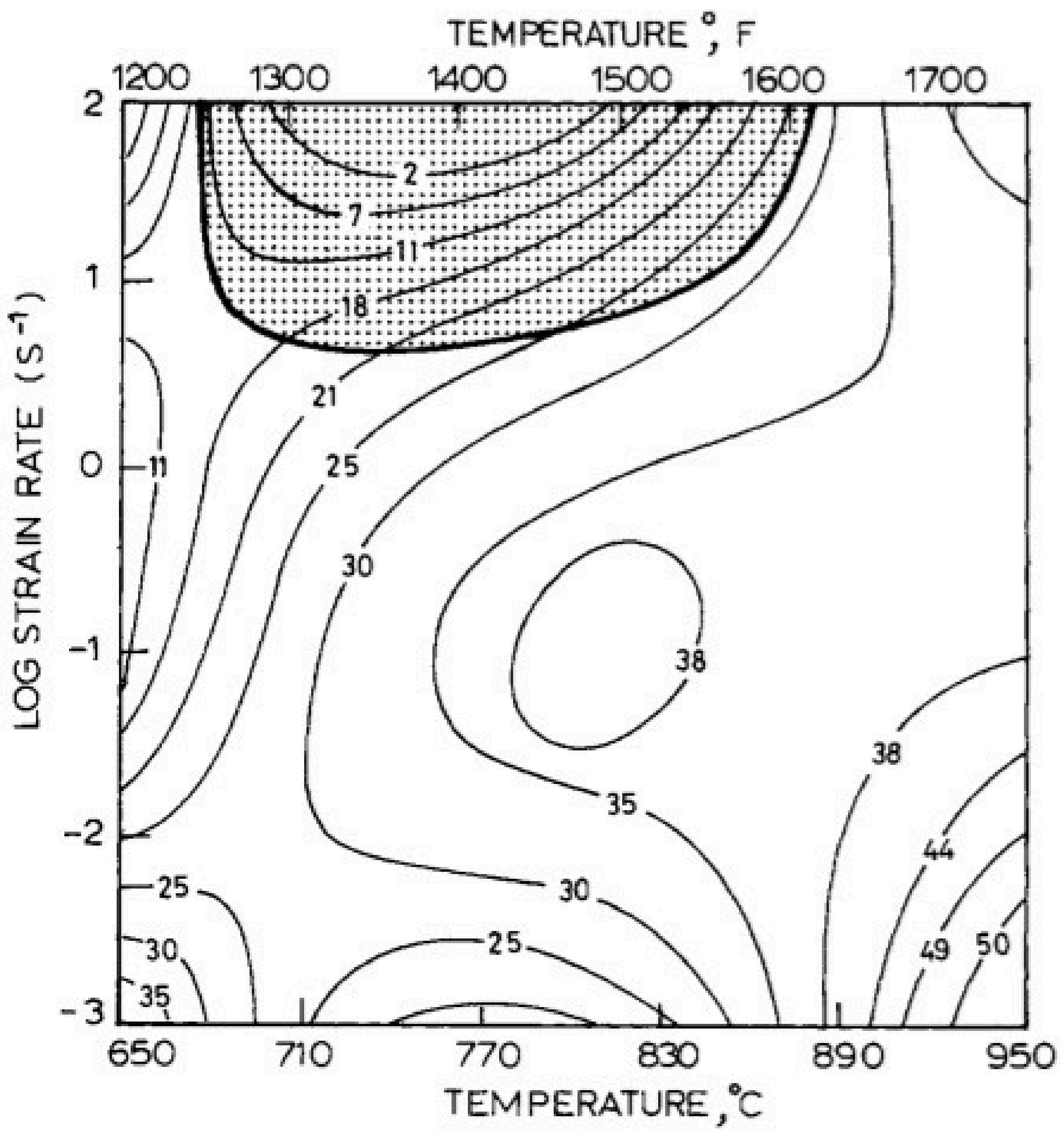
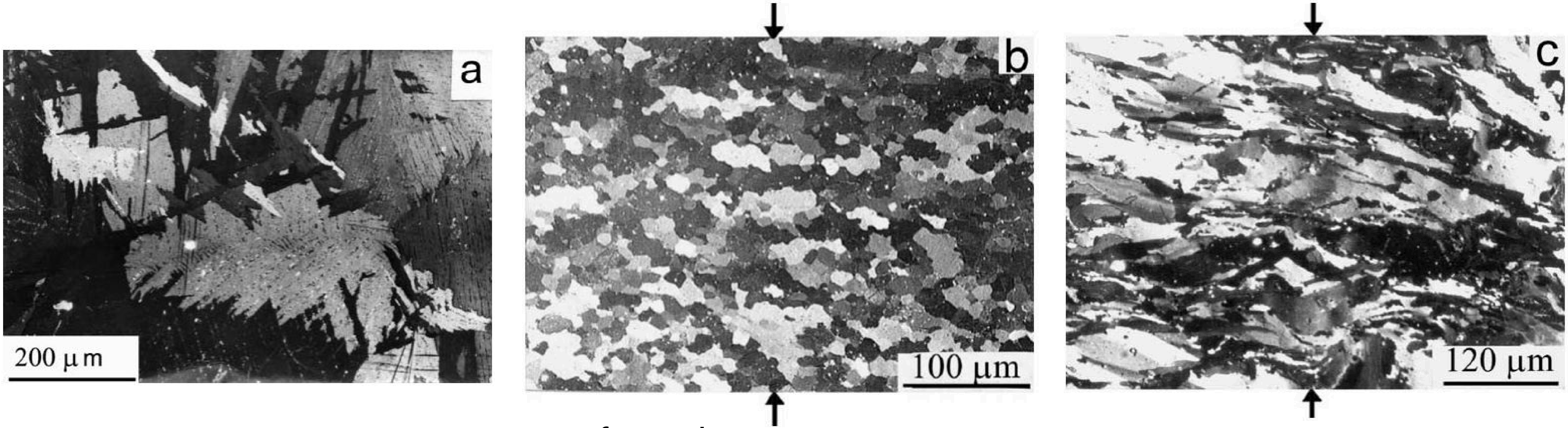


Fig. 8.2.1 Processing map of zircaloy-2 at a strain of 0.5. Contour numbers represent percent efficiency of power dissipation. Shaded region represents instability.

Metallurgical Interpretation and Processing Conditions for Zircaloy-2

Manifestation	Temperature, °C	Strain rate, s^{-1}
Dynamic recrystallization	800	0.100
Dynamic recovery	650	0.001
Superplasticity	950	0.001
Flow localization	675-880	> 5
Optimum Conditions: 800°C and 0.1 s^{-1}		

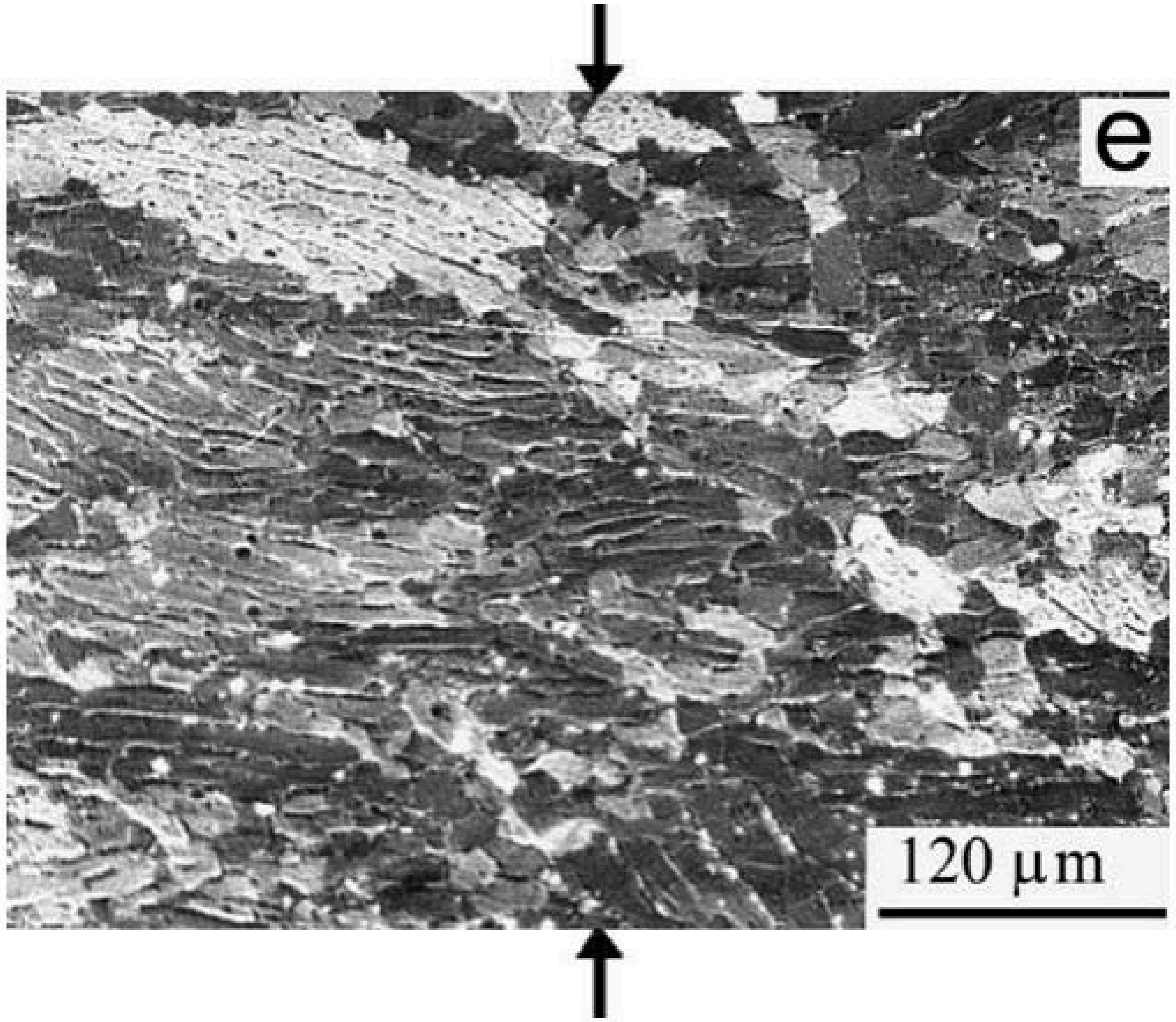
Optical micrographs of Zircaloy-2



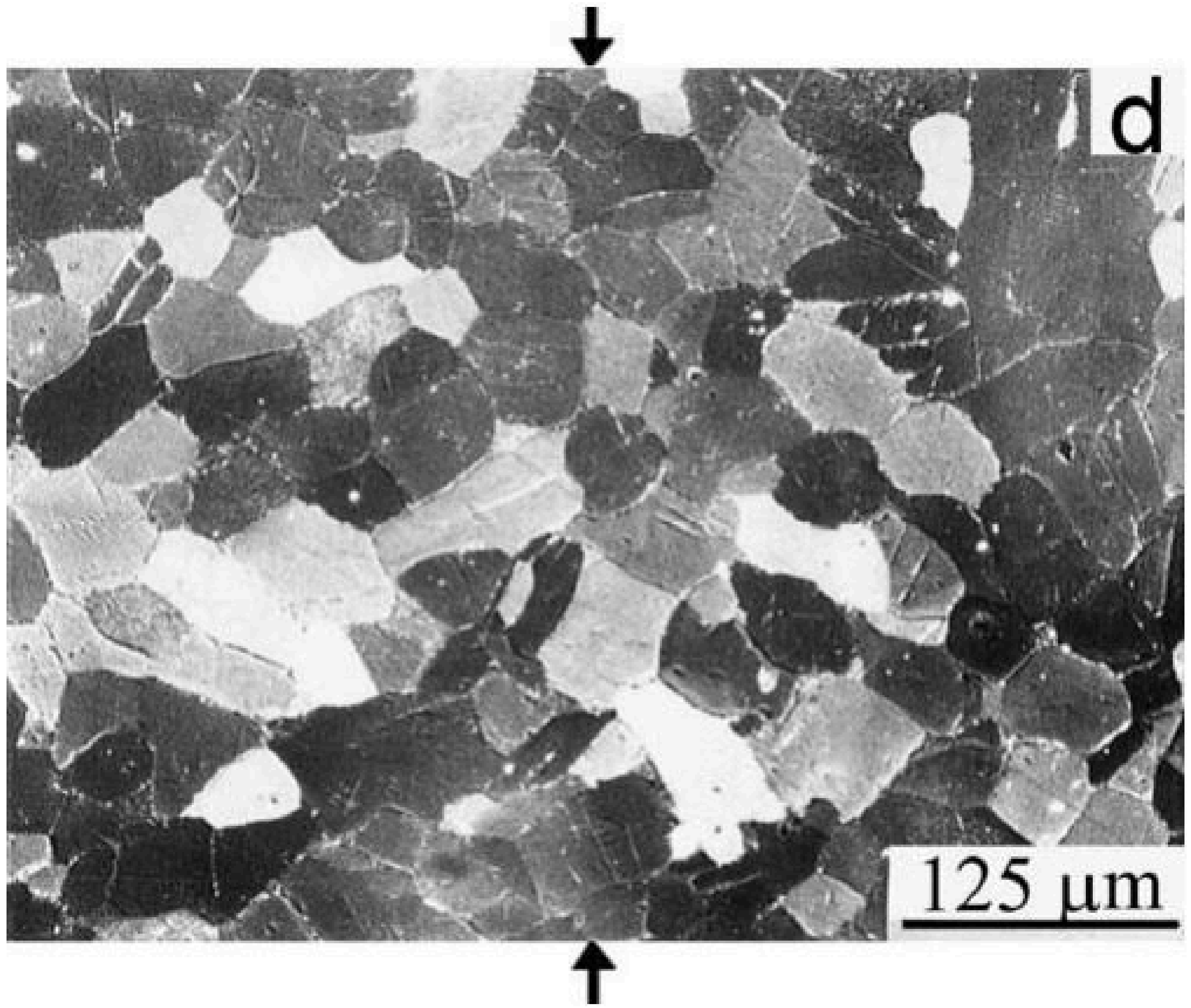
Starting microstructure which consists of transformed ß

Deformed microstructures at 800 °C-0.1 s,

Deformed microstructures at 650 °C-0.001 s'



Deformed microstructures at
950 °C-0.001 s¹,



Deformed microstructures at
900 °C-0.1 s

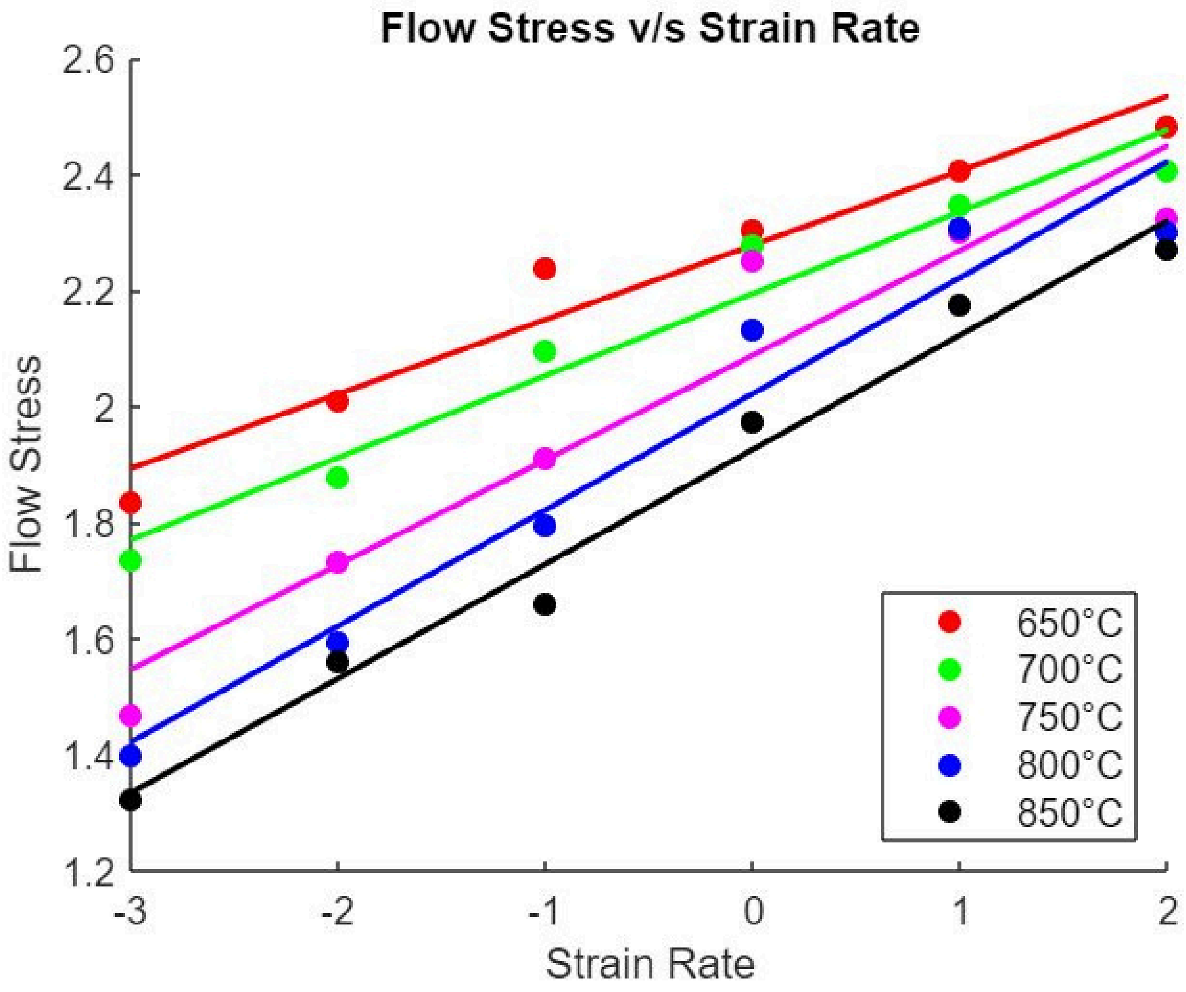
Alpha-Zirconium

Material: Zirconium

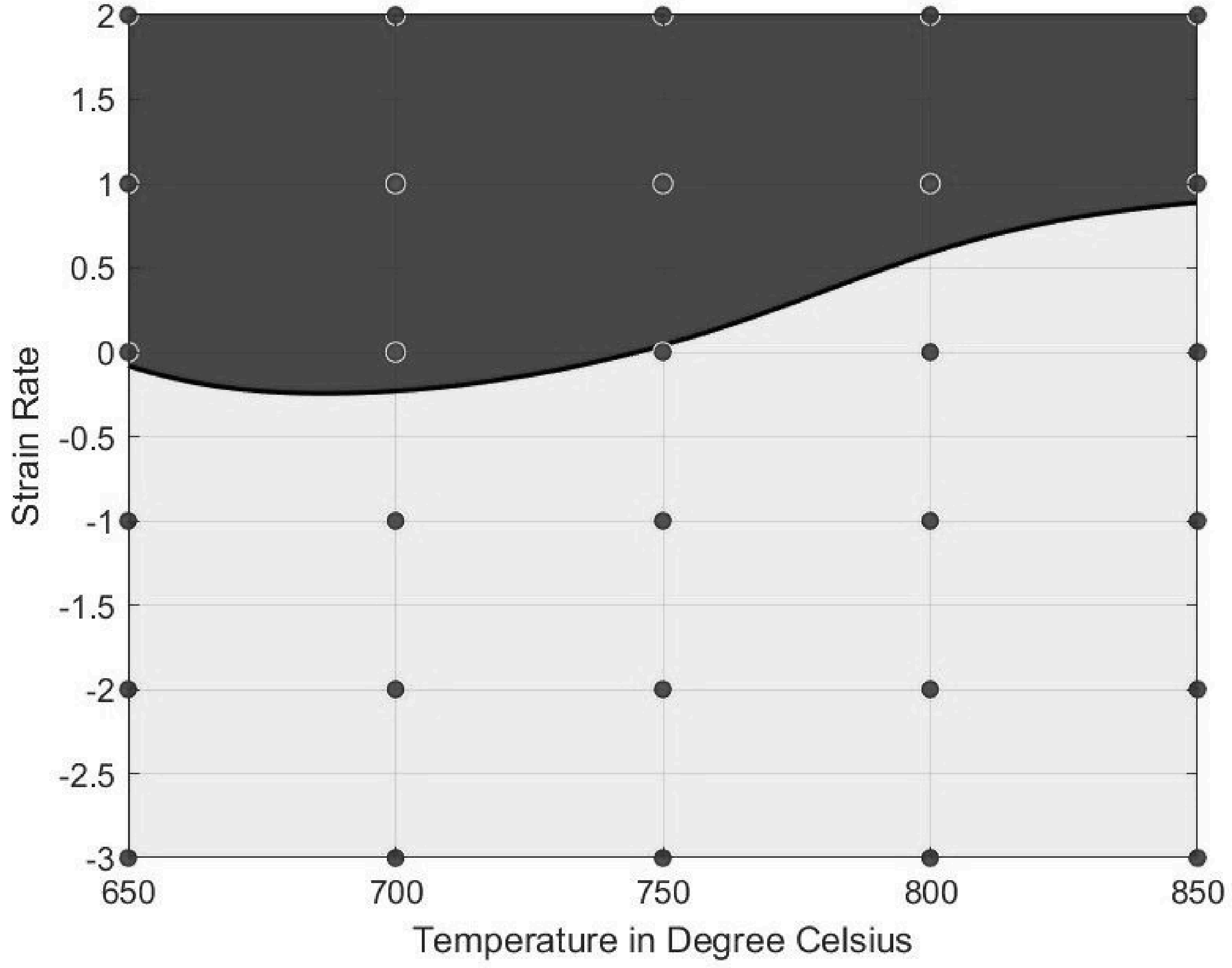
Composition: O-1000 ppm, Zr-bal.

Prior History: Reactor grade zirconium was used in this study. Test samples sealed under helium were beta quenched from 1030°C.

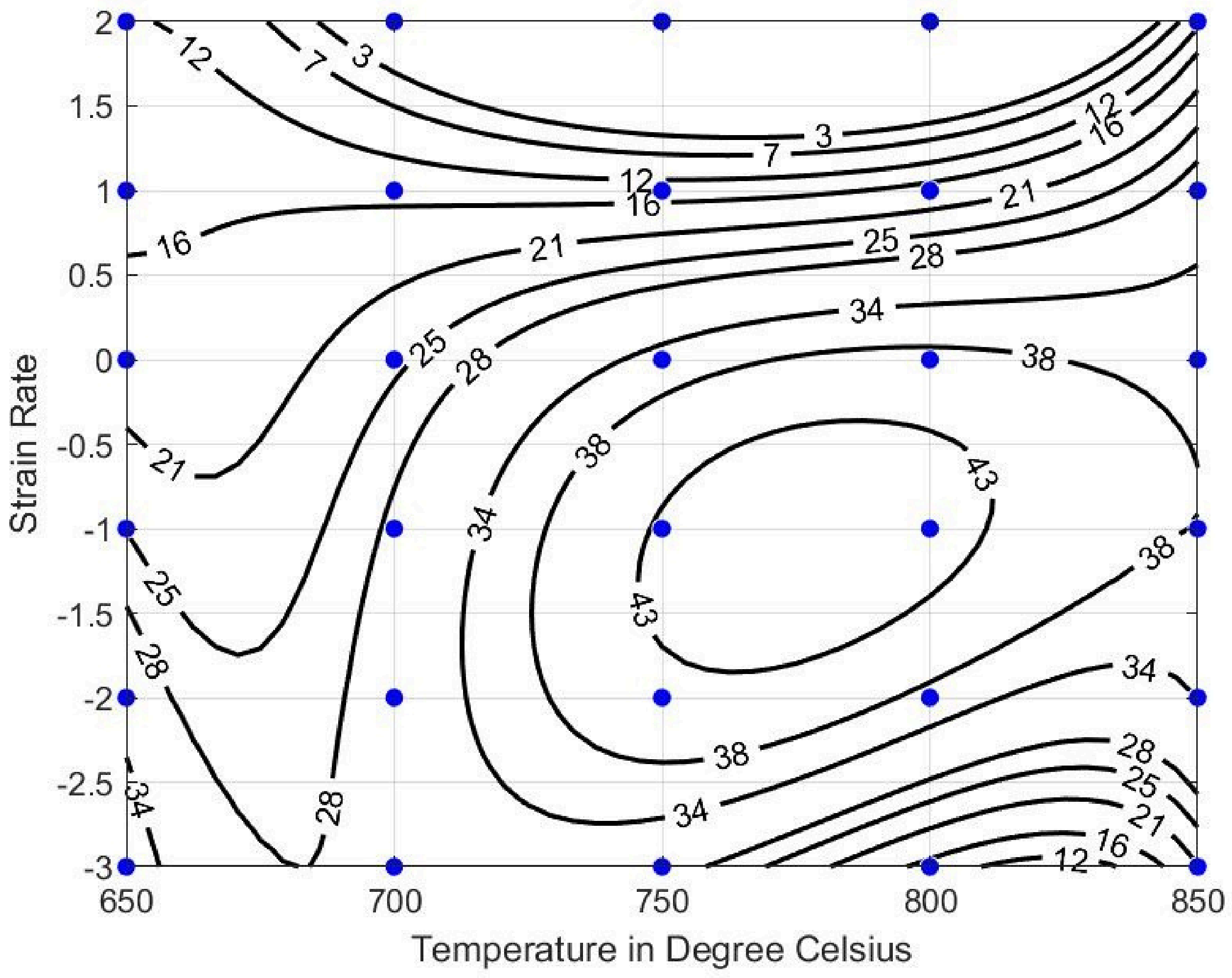
FLOW STRESS VS STRAIN RATE



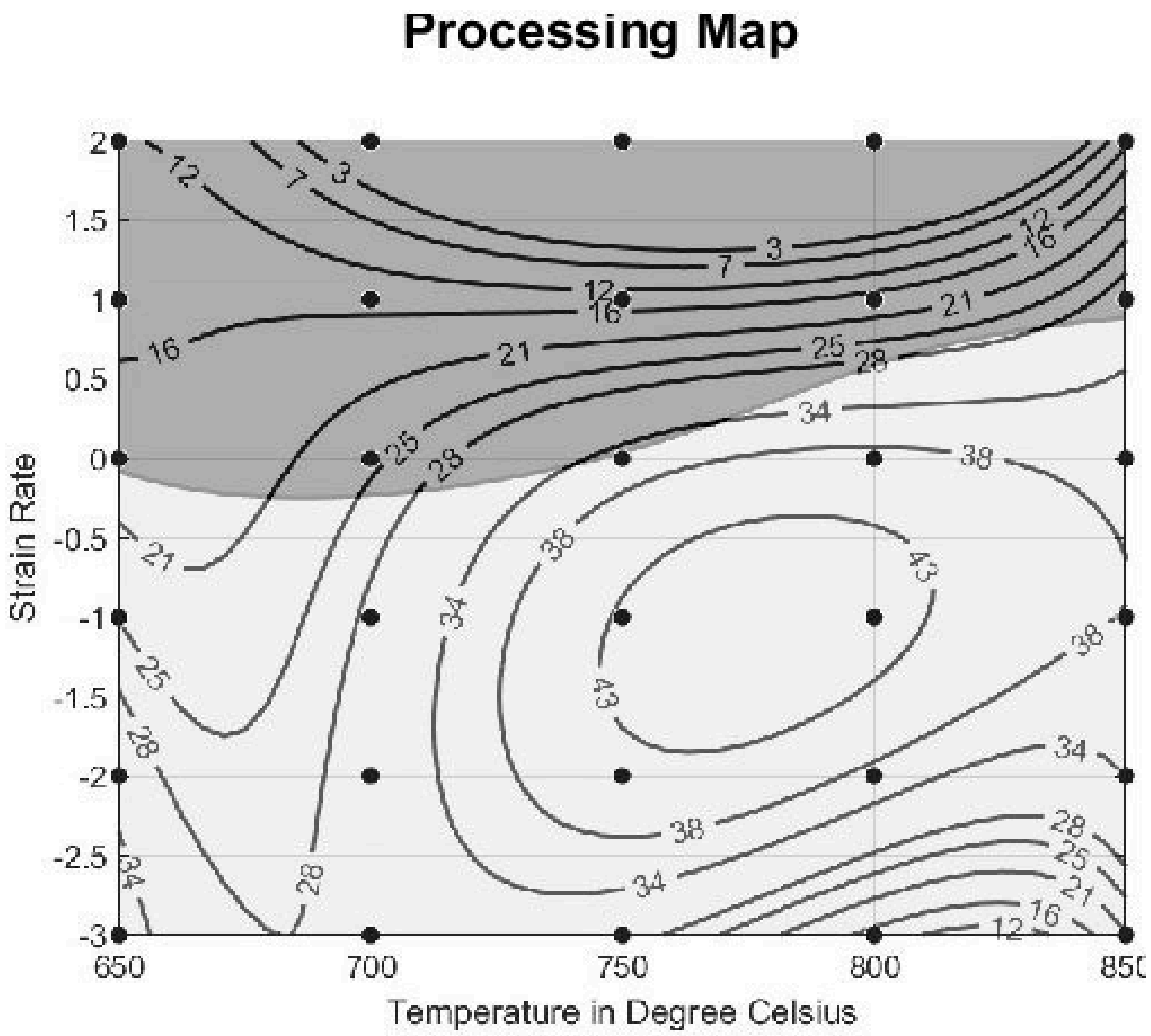
INSTABILITY MAP



POWER DISSIPATION MAP



PROCESSING MAP



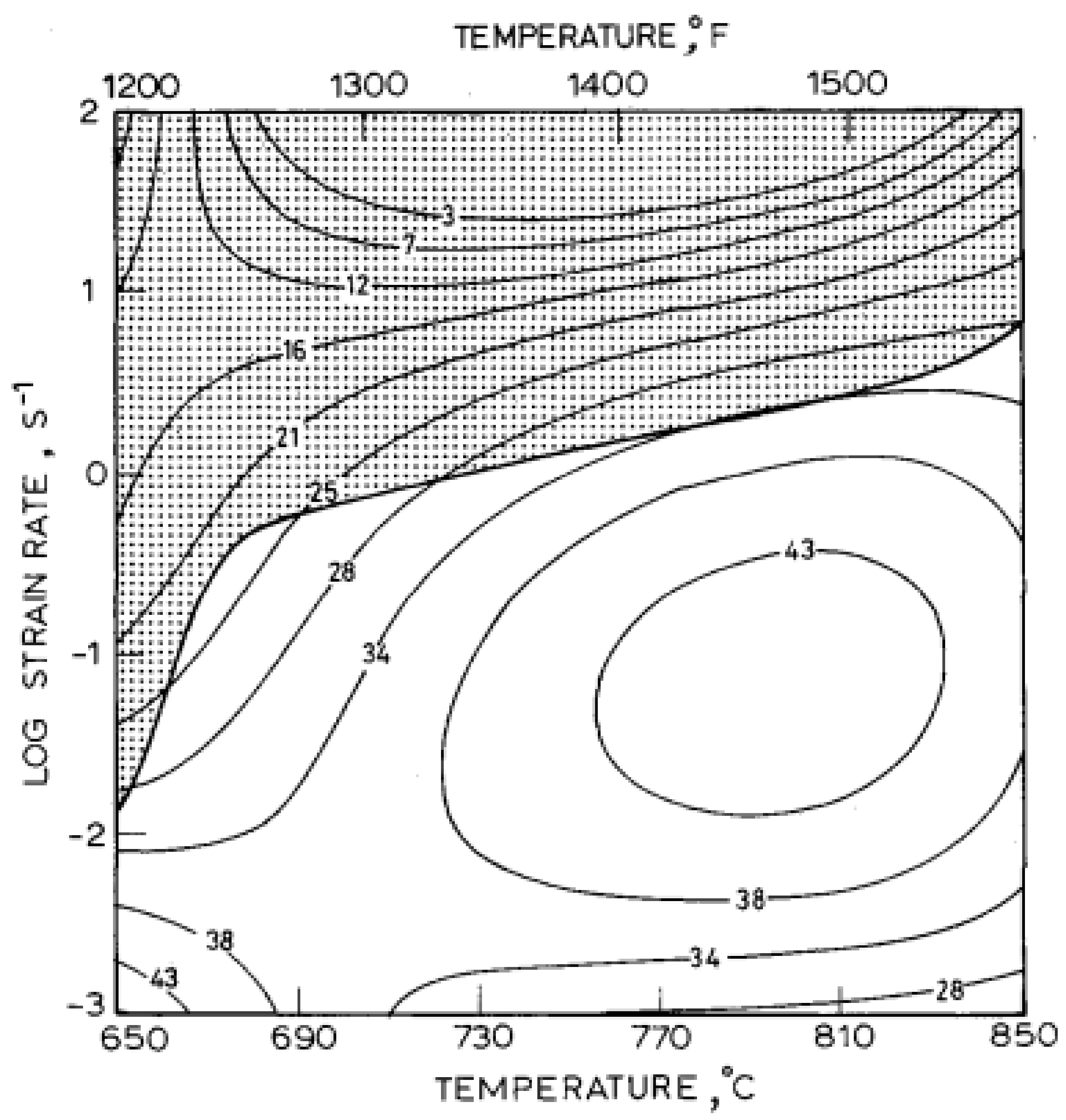
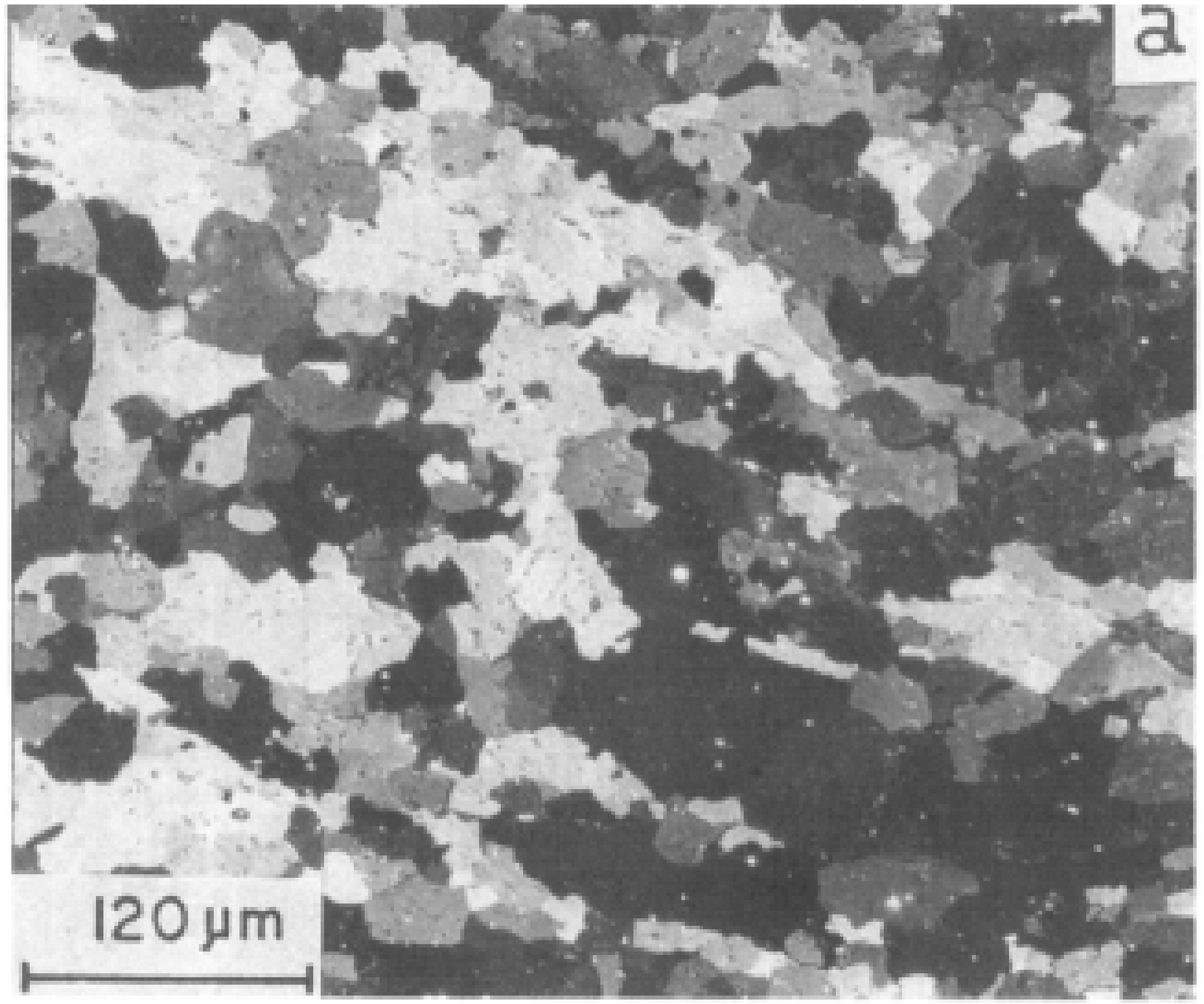


Fig. 8.1.1 Processing map for α-zirconium at a strain of 0.3. Contour numbers represent percent efficiency of power dissipation. Shaded region corresponds to flow instability.

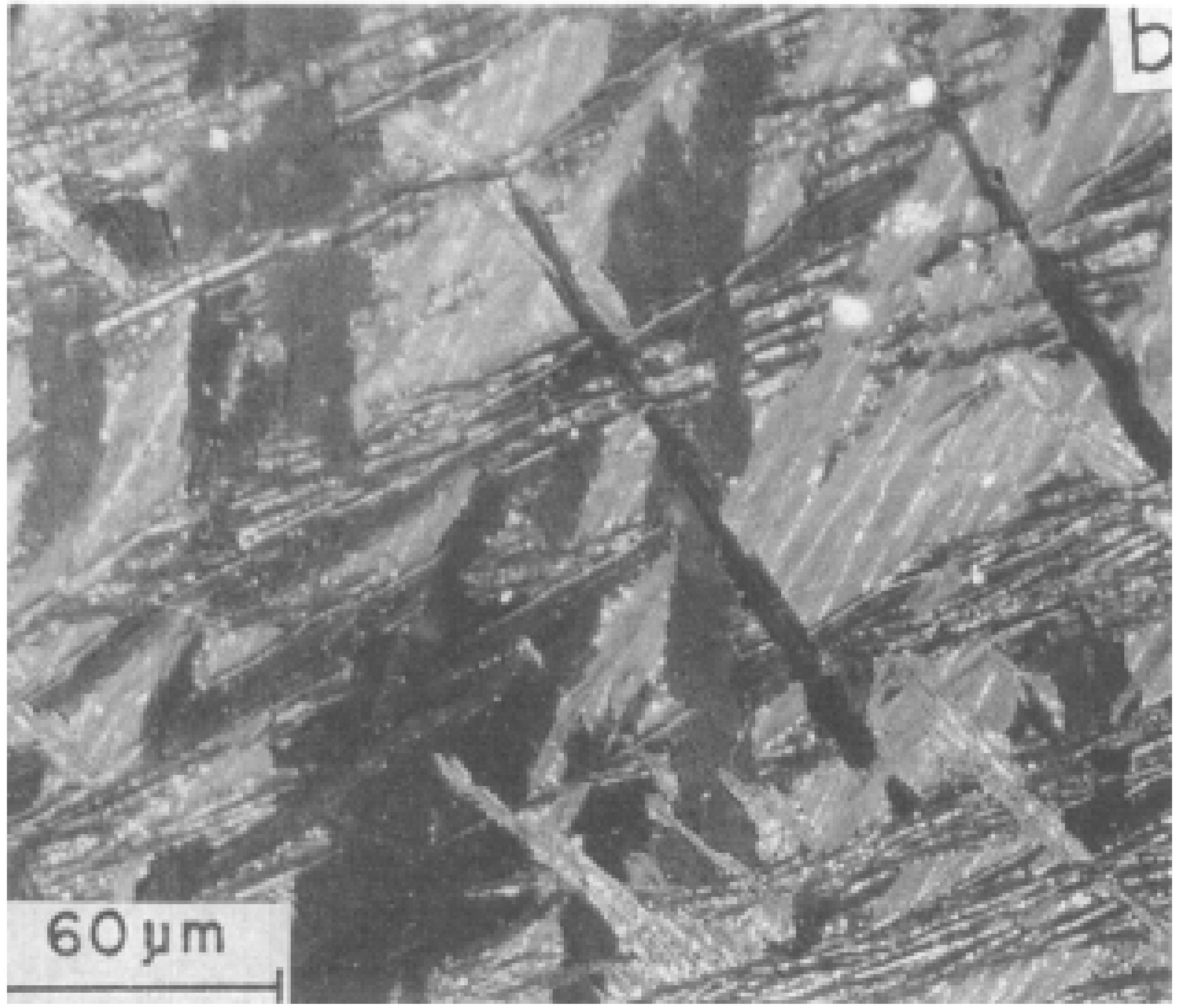
Metallurgical Interpretation and Processing Conditions for hot working of α-Zirconium.

Manifestation	Temperature, °C	Strain rate, s^{-1}
Dynamic recrystallization	730-850	0.01 - 1
Texture induced dynamic recovery	650	0.001
Microstructural instabilities	> 670	> 1
Optimum Conditions: 800°C and 0.01 s^{-1}		

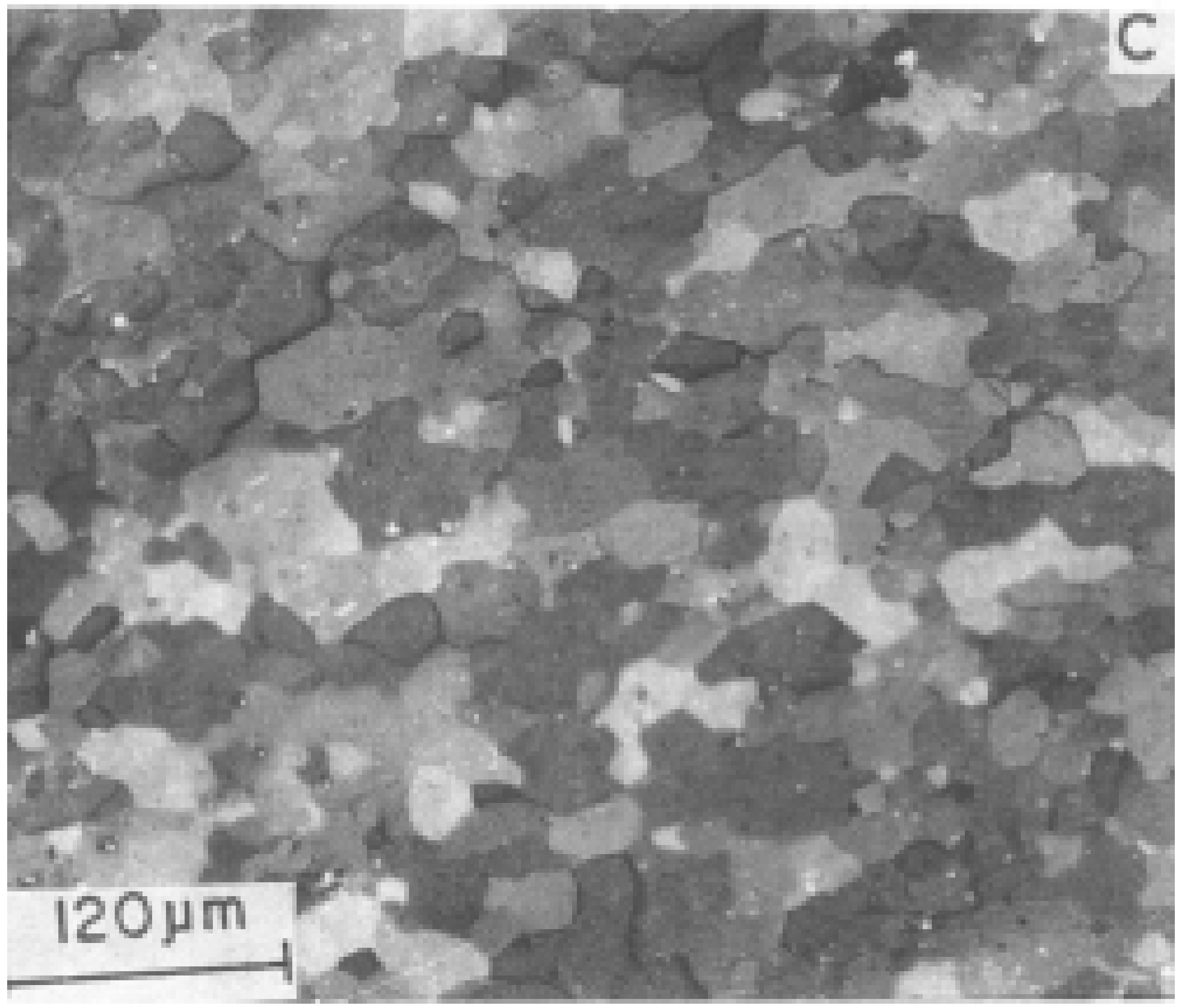
Optical micrographs of alpha-Zirconium



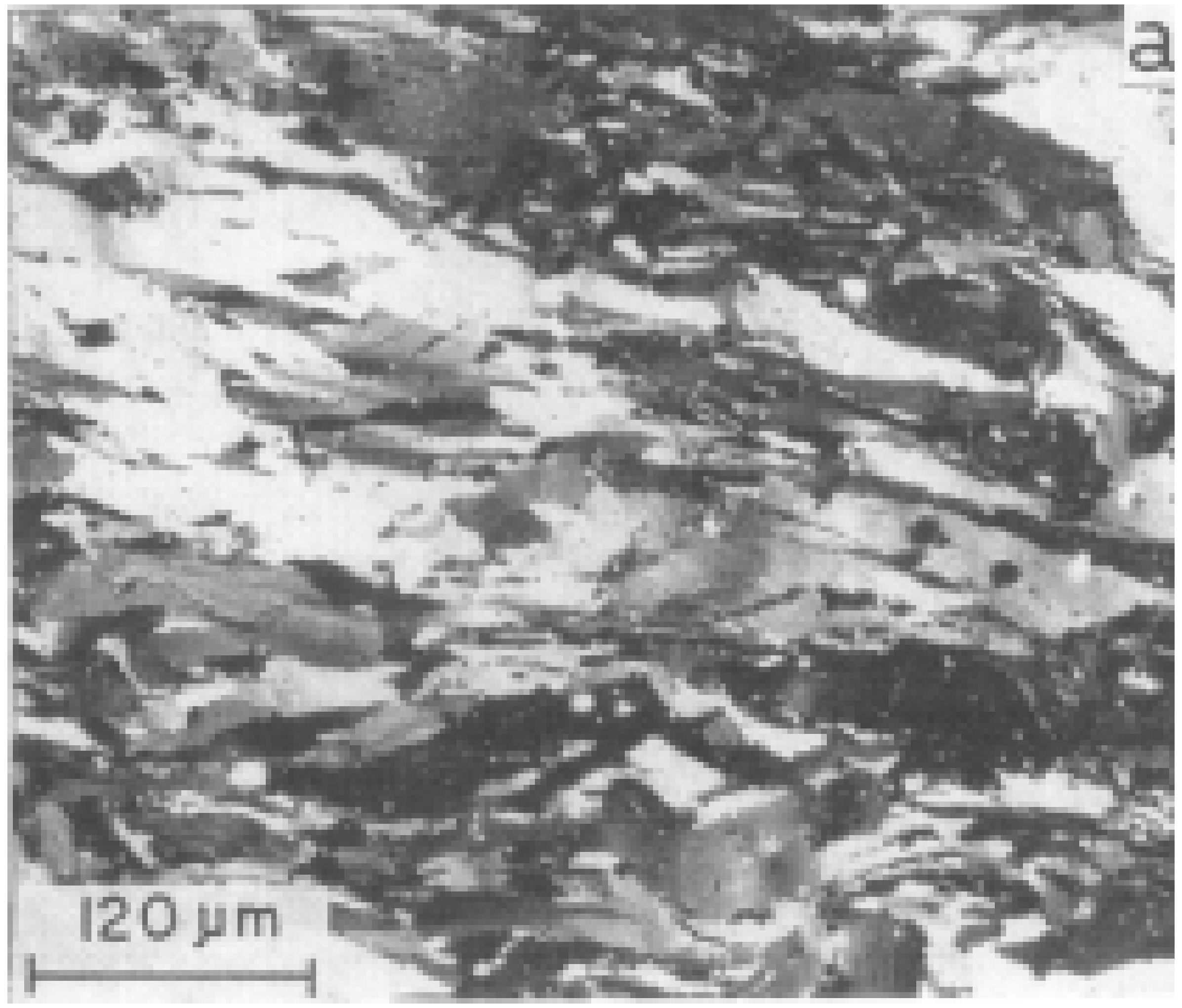
Optical micrographs of (a) dynamically recrystallized alpha-zirconium at 800°C and 0.1s−1to a strain of 0.3



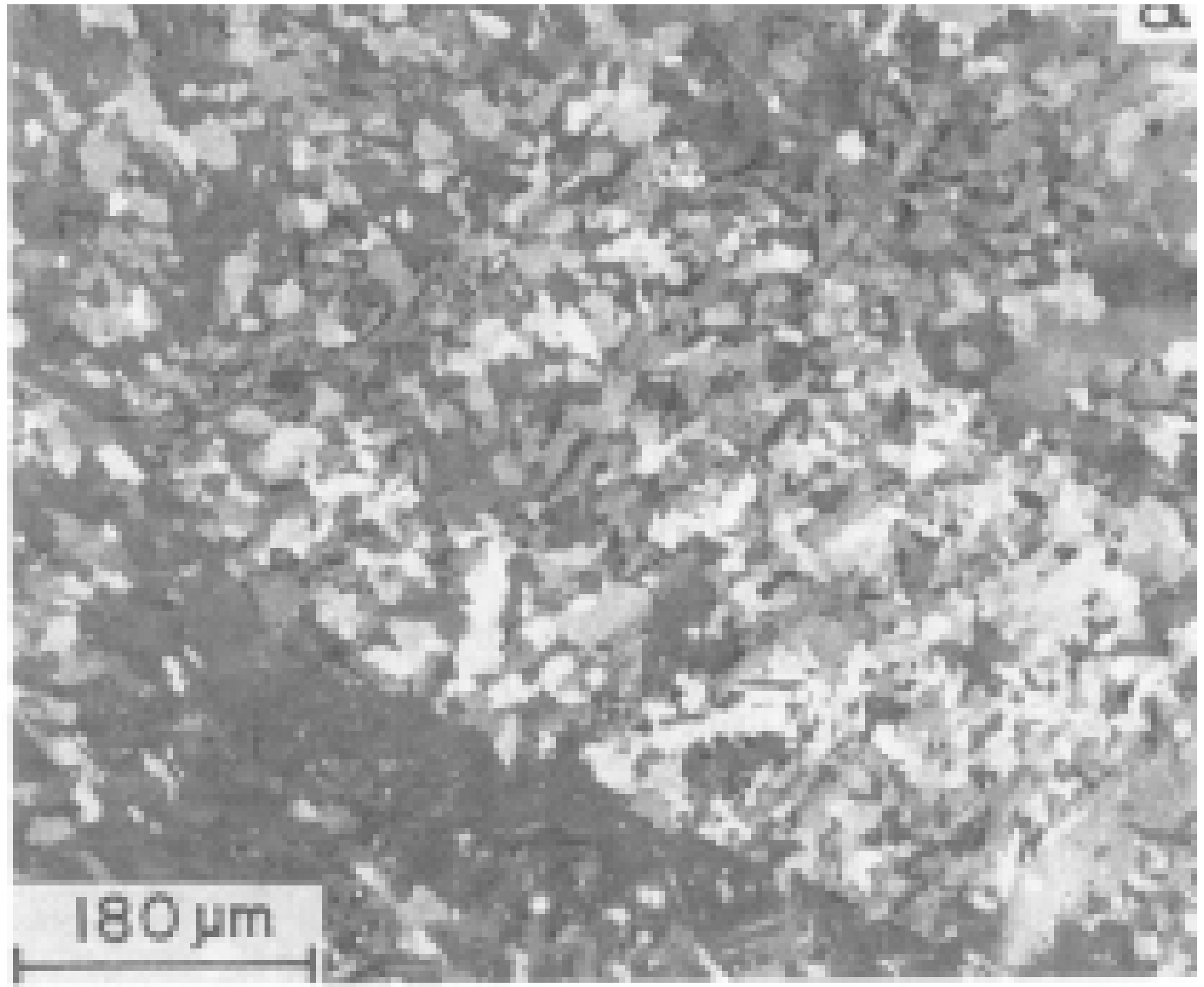
Optical micrographs of (b) starting microstructure showing beta-quenched alpha-zirconium



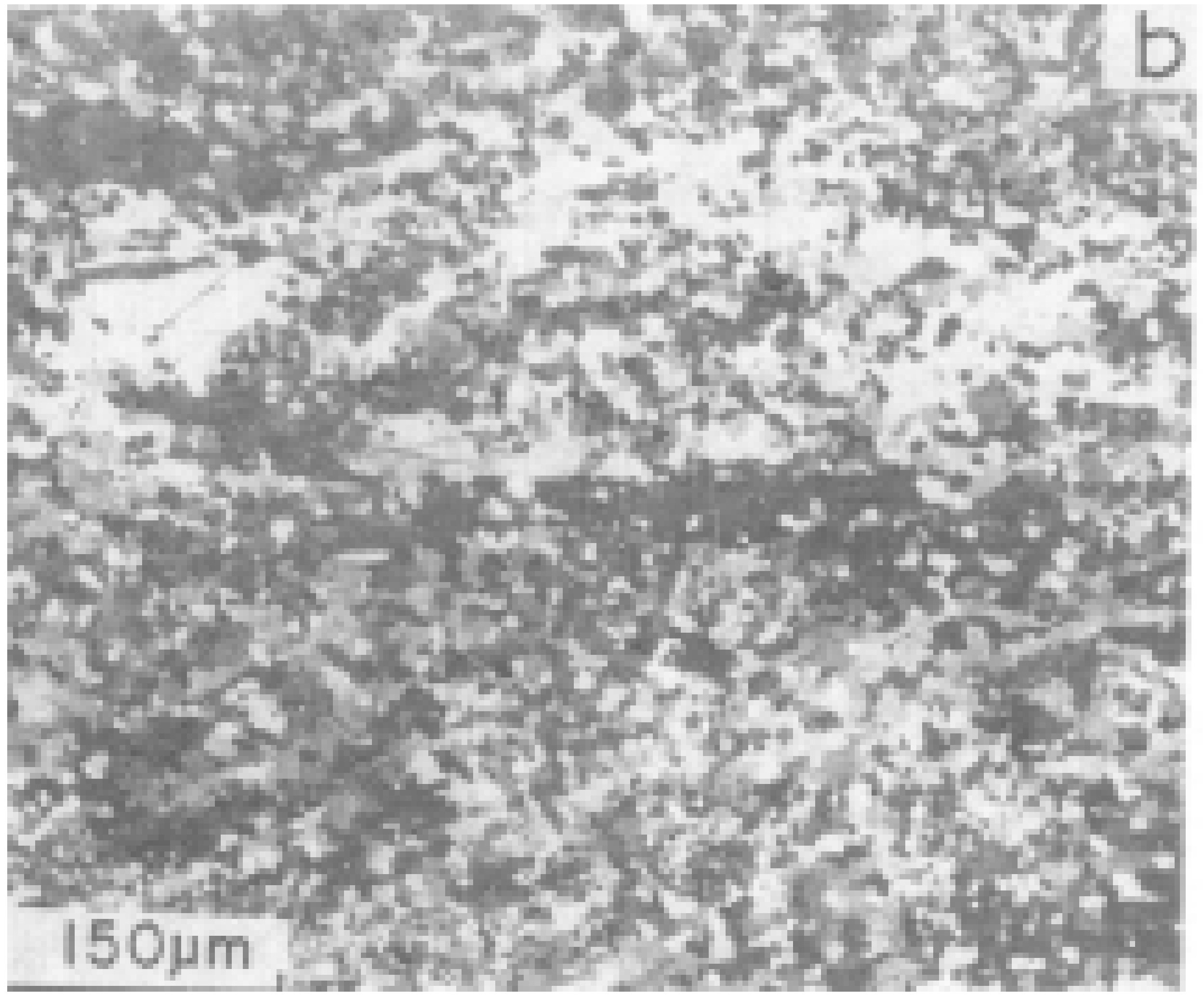
Optical micrographs of (c) a completely recrystallized structure of deformed alpha-zirconium at 800°C and furnace cooled.



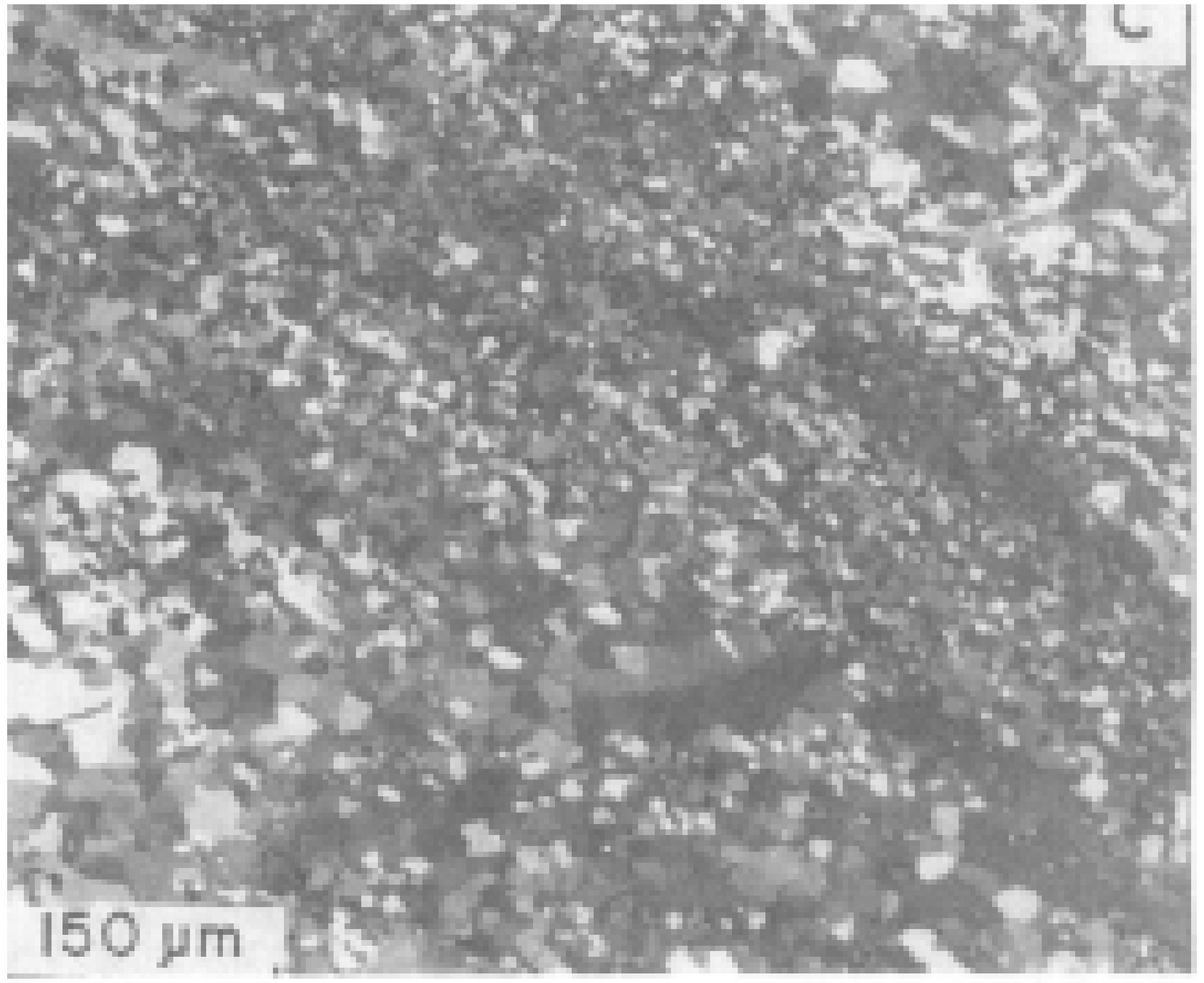
Dynamically recovered structure in alpha-zirconium deformed to a strain of 0.7 at 650°C and at a strain rate of 0.001 s-1



Optical micrographs of the samples deformed at 700°C showing manifestations of instability in the form of localized shear bands on deformation at (a) 10 s -1



Optical micrographs of the samples deformed at 700°C showing manifestations of instability in the form of localized shear bands on deformation at (b) 1 s -1



Optical micrographs of the samples deformed at 700°C showing manifestations of instability in the form of localized shear bands on deformation at (c) 100 s -1

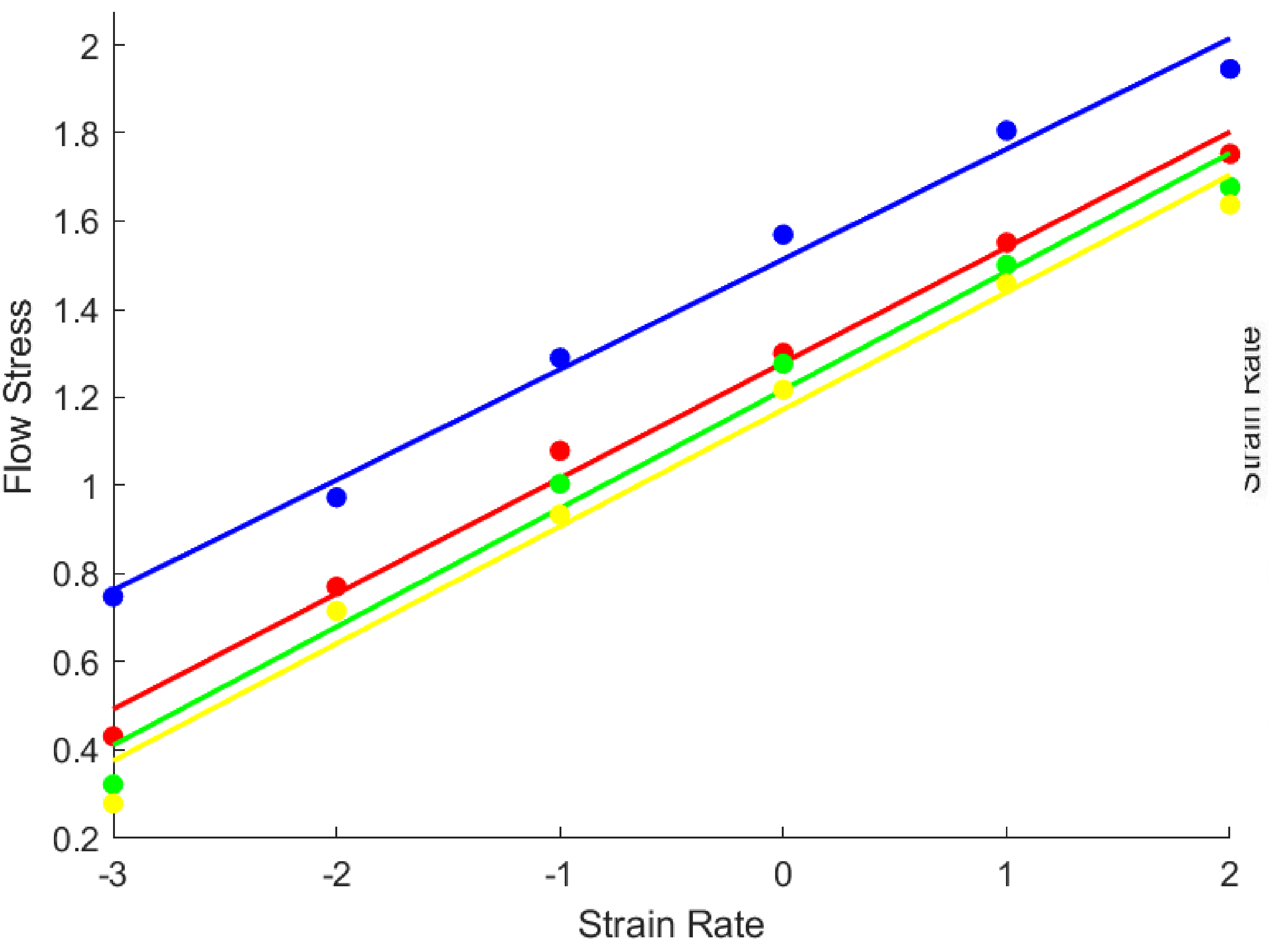
Beta-Zirconium

Material: Zirconium

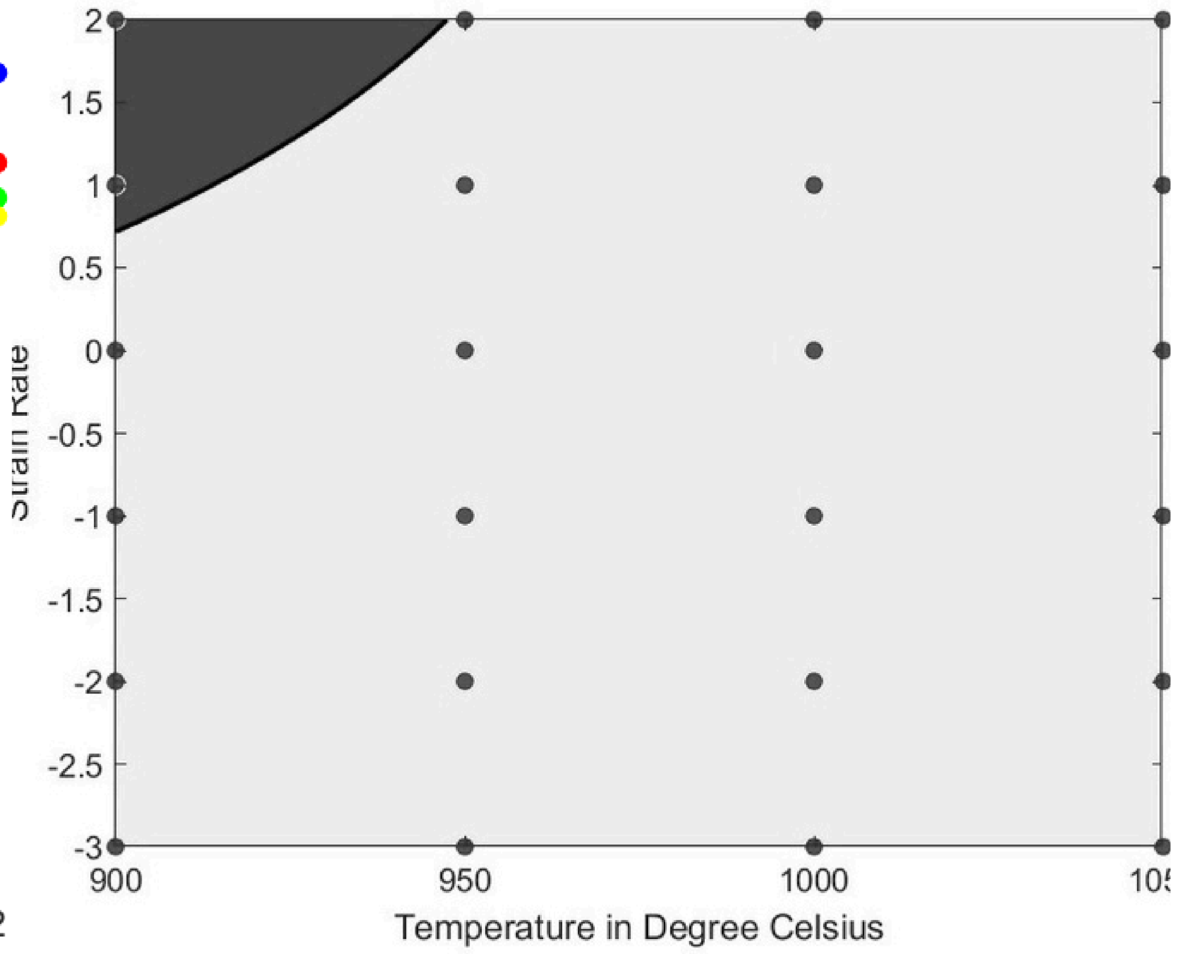
Composition: O-1000 ppm, Zr-bal.

Prior History: Reactor grade zirconium was used in this study. Test samples sealed under helium were beta quenched from 1030°C.

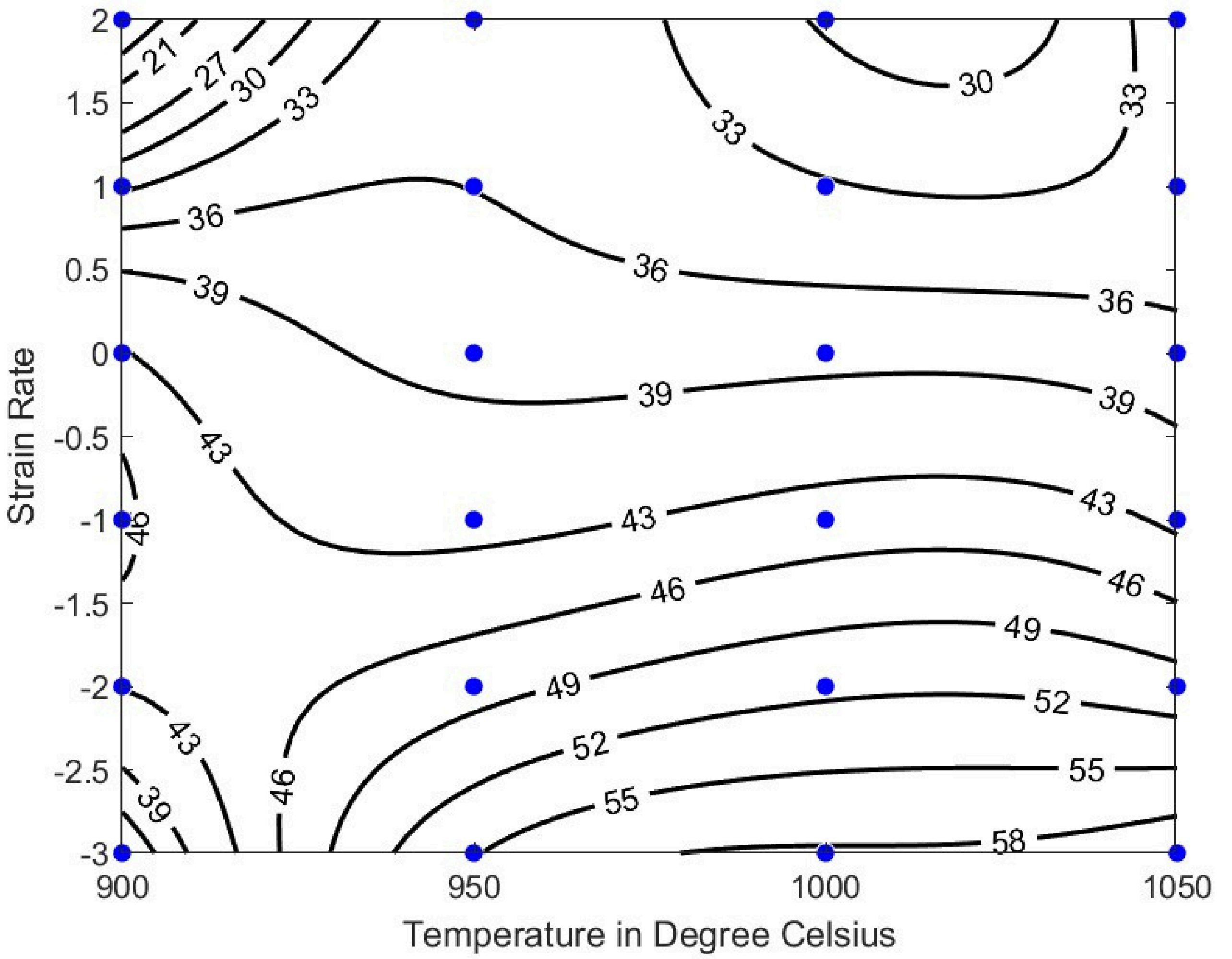
FLOW STRESS VS STRAIN RATE



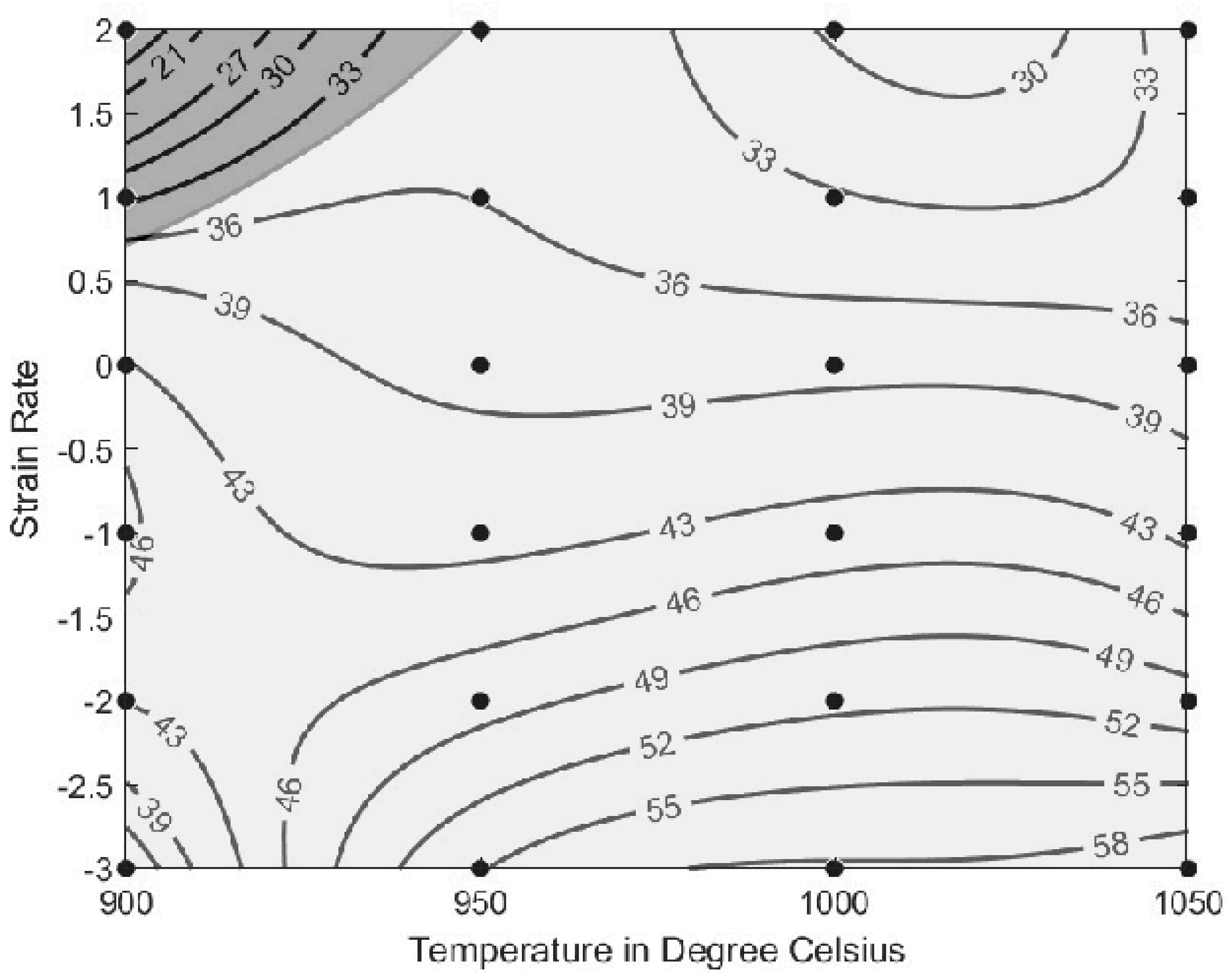
INSTABILITY MAP



POWER DISSIPATION MAP



PROCESSING MAP



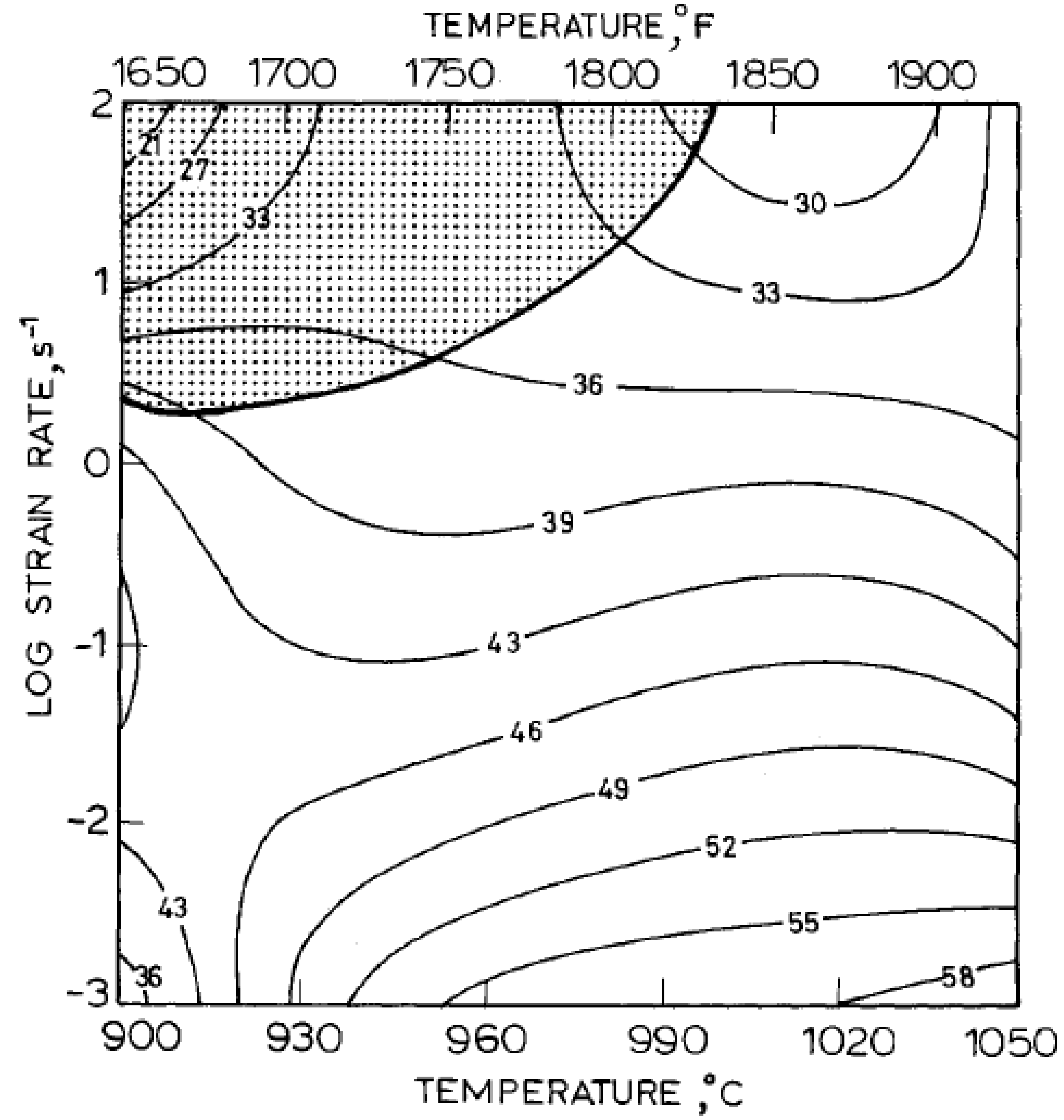


Fig. 8.1.2 Processing map for β-zirconium at a strain of 0.4. Contour numbers represent percent efficiency of power dissipation. Shaded region corresponds to flow instability.

Metallurgical Interpretation and Processing Conditions for β-zirconium.

Manifestation	Temperature, ºC	Strain rate, s^{-1}
Superplasticity	925-1050	< 0.1
Flow instabilities	900-1000	> 2 s^{-1}
Optimum Conditions: 1025 ºC and 0.001 s^{-1}		

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THANK YOU